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EFFECT OF MELT FLOW INDEX ON THE IMPACT RESISTANCE, DIMENSIONAL VARIATION, AND MECHANICAL PROPERTIES OF INJECTION MOLDED POLYCARBONATE

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13. ABSTRACT *(Maximum 200 words)*
Recent advances in manufacturing technologies permit the production of large plastic components by injection molding. The techniques required to manufacture aircraft transparencies by injection molding are currently being developed as part of the Frameless Transparency Program. To evaluate the effect of melt flow index (MFI)on the behavior of injection molded material, panels were molded from Dow Calibre 300 resin with various MFIs. Some of the panels were dimensionally mapped to evaluate the effects of MFI variation on shrinkage. Tensile tests performed on coupons cut from the panels were used to evaluate the effect of MFI variation on strength and elongation. Birdstrike tests on the panels were used to evaluate the effect of MFI variation on impact resistance. Results and conclusions of the test programs are presented.

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FOREWORD

The efforts reported herein were performed by the Aerospace Mechanics Division of the University of Dayton Research Institute (UDRI), Dayton, Ohio. The work was sponsored by the Flight Dynamics Directorate of the Air Force Wright Laboratory Wright-Patterson Air Force Base, Ohio, under Air Force contracts F33615-84-C-3404, F33615-92-C-3400, and F33615-92-C-3404. Air Force administration and technical direction were provided by Messrs. Richard A. Smith and William R. Pinnell, WL/FIVR.

The work described herein was conducted during the period August, 1992, through May, 1993. UDRI project supervision was provided by Mr. Blaine S. West, Head, Aerospace Mechanics Division; and Mr. Gregory J. Stenger, Leader, Structures Group. Technical effort was accomplished with Messrs. Gregory J. Stenger and Geoffrey J. Frank as Principal Investigators. Dimensional mapping was performed at Giddings & Lewis, Inc., Dayton, Ohio. Bird impact testing was performed in the University of Dayton Research Institute Impact Physics Laboratory, and tensile coupon testing was performed in the Structures Laboratory.

The authors would like to thank Mr. Pinnell for his comments, insights, and technical direction during the course of this project. Additionally, the authors wish to thank Messrs. Daniel R. Bowman and Ronald K. Newman for their technical support in conjunction with the experimental program, and Dr. Robert A. Brockman and Mr. Thomas W. Held for their technical direction in the analytical portion of this effort.

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SECTION 1
INTRODUCTION

The primary manufacturing technique for the current generation of high-performance aircraft transparencies consists of extruding flat sheets of plastic, laminating these sheets with interlayers, and bending the laminated assembly into the desired shape. Fasteners at the edges of the assemblies are used to mount the transparencies into metal frames. The holes near the transparency edge which are required for installing the fasteners tend to degrade the performance of the transparency during a bird impact. The transparency frame might be eliminated and improved birdstrike resistance achieved if latch mechanisms and edge reinforcements could be integrated into the transparency panel. Elimination of the frame, however, is not compatible with existing transparency manufacturing techniques.

The techniques required to manufacture aircraft transparencies by injection molding are being developed as part of the Air Force effort to develop technology for directly-formed and frameless aircraft transparencies. This effort has been referred to as the Frameless Transparency Program (FTP). As part of this program, candidate materials, injection molding parameters, and different configurations for attaching frameless transparencies to aircraft are being evaluated. During the next phase of the FTP, a windshield size transparency having a mold-line shape based on the forward half of the current F-16 aircraft canopy will be molded. This Confirmation Frameless Transparency (CFT) will not be a flight item, but will become the subject of extensive optical and structural testing. CFT test results will form the basis for confirming an Analytical Design Package (ADP), which is currently under development, for the directly-formed and frameless transparency concept.

Previous evaluations have indicated that, using the types of molding processes developed to date, the most promising materials for molding the CFT are Dow Calibre 300-class polycarbonates [1, 2]. Molding trials were accomplished in April, 1992, to produce injection molded panels from four resins in three panel configurations. Testing and evaluation of the panels were subsequently accomplished to investigate the effects of melt flow index (MFI) and

panel thickness on material moldability, impact resistance, molded part shrinkage, and material tensile properties.

A series of flat panels and cones was molded at Envirotech Molded Products using Dow Calibre 300 resins with MFIs of 4, 6, and 15. Additional panels and cones were molded with an experimental resin, Dow XU73093-5.5. The summary of the molding effort is presented in Section 2.

Three molds and 39 panels were dimensionally mapped using a Coordinate Measuring Machine (CMM). Shrinkage, thickness, and overall dimensions were calculated based on this mapping data. Results from the dimensional mapping are presented in Section 3, as are conclusions concerning the repeatability of panel dimensions and the effect of variations in resins.

Eighteen polycarbonate panels were birdstrike tested at the University of Dayton Research Institute. Triangulation techniques were used to obtain deflection-time-history data from the recorded birdstrike event. An explicit finite element analysis code was employed to predict the impact response analytically. Results and conclusions from the test program, triangulation, and analysis are presented in Section 4.

A total of 88 tensile coupons cut from 8 conical panels and 16 flat panels were tested. Data from these tests were used to compare the Dow resins. Results of the tests are presented in Section 5.

SECTION 2
MOLDING OF PANELS AND CONES

2.1 Introduction

This effort was initiated in March, 1992, to support a larger WL/FIVR effort, the Directly Formed and Frameless Aircraft Transparency Technology Development Program (i.e., the Frameless Transparency Program, or FTP). This subject effort is the latest in a series of transparent panel molding and testing efforts to support the FTP (Figure 1). With this in mind, a short discussion on the previous support efforts is in order.

2.1.1 Background

2.1.1.1 Initial Process Evaluation

Preceding the FTP, WL/FIVR funded Loral Defense Systems in a program (October 1985 - September 1988) to identify and demonstrate a forming process for large, thick-walled, transparent parts. The process selected as a result of the Loral effort was a low pressure, long cycle, injection molding process. Several hundreds of flat and conical panels (Figure 2) were injection molded using several different materials and a wide variety of processing parameters (temperatures, pressures, shot size, cycle times, etc.) Molding was accomplished at Envirotech Molded Products (formerly EIMCO), Salt Lake City, Utah. Panels with desirable characteristics were typically molded from clear polycarbonate at approximately 750 psi with cycle times in the range of 30-45 minutes. The Loral effort is documented in Reference 1.

2.1.1.2 Frameless Transparency Program

Upon completion of the Loral effort, WL/FIVR initiated the FTP. The objectives of the FTP are to develop the Analytical Design Package (ADP), design the Confirmation Frameless Transparency (CFT), and confirm the ADP by directly forming (injection molding) and testing the CFT.

DIRECTLY FORMED and FRAMELESS AIRCRAFT TRANSPARENCY TECHNOLOGY DEVELOPMENT

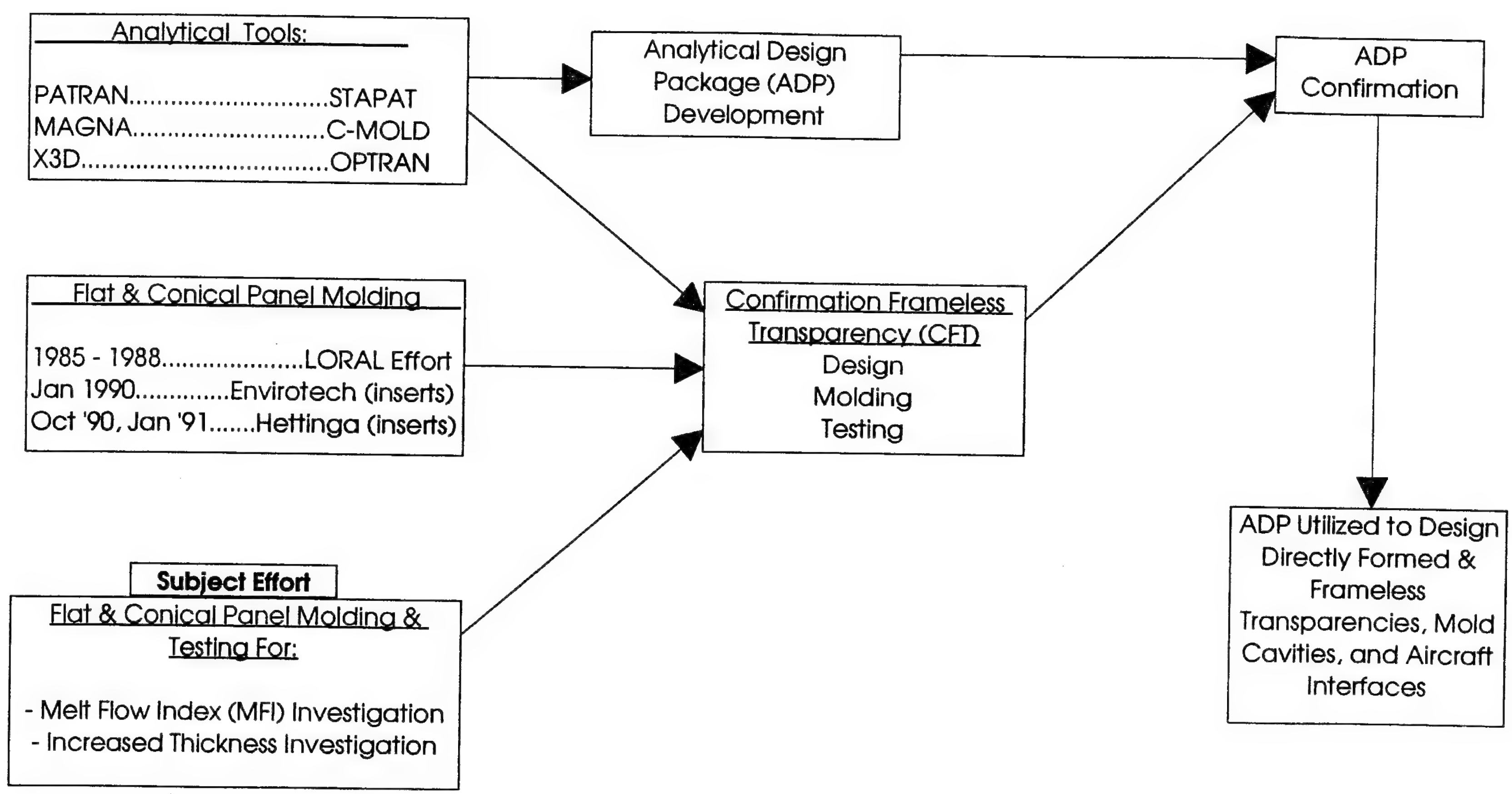
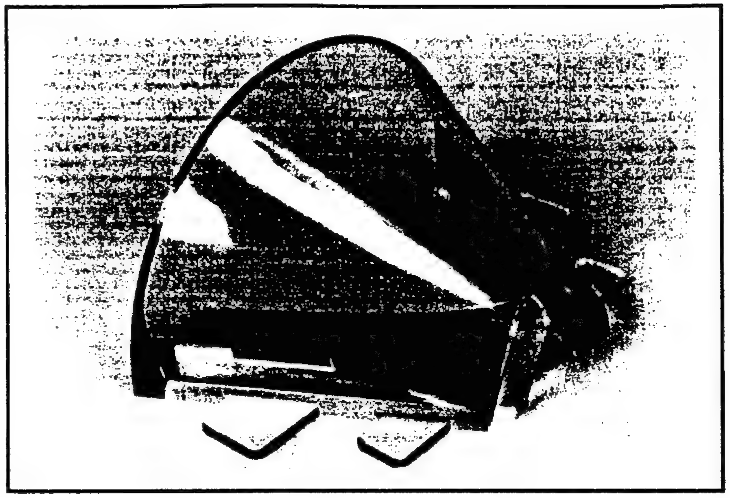


Figure 1. Directly Formed and Frameless Aircraft Transparency Technology Development

DIRECTLY FORMED FRAMELESS AIRCRAFT TRANSPARENCIES
PROCESS DEVELOPMENT PANELS



Conical Panel

- **1/2 in thick**
- **2 in thickened edges**

Flat Panel

- **1/2 and 3/4 in thick**
- **2 in thickened edges**
- **Simulated Juncture**

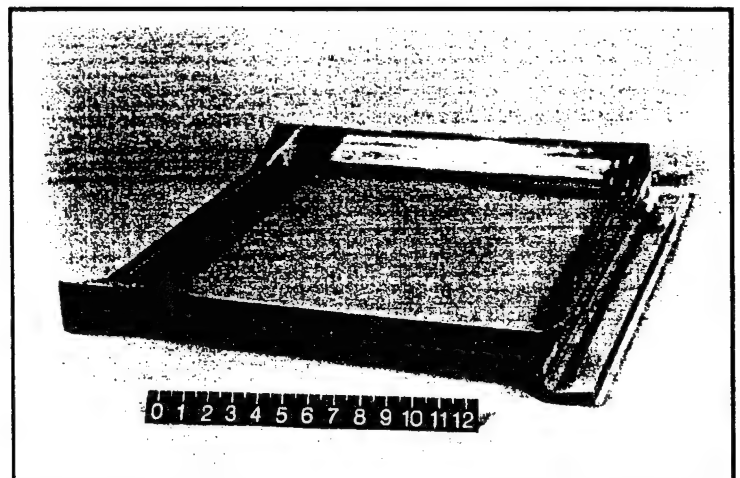


Figure 2. Conical and Flat Panels

The ADP is an integrated package of established computer based analytical design and analysis software. This package includes software for Computer Aided Engineering (CAE), structural and geometric modeling, finite element dynamic structural analysis, thermal analysis, optical analysis, and molding simulation. The ADP provides the capability for producing frameless transparency designs entirely through iterative analysis. The ADP produces data needed for the design of aircraft interfaces and data needed for the mechanical design of molds. The ADP also analytically establishes molding process parameters for selected materials. The ADP is the main "product" of the FTP.

The CFT (Figure 3) was designed using components of the ADP. The CFT is a test and verification part much larger than the panels molded during the Loral effort. Although the CFT was not designed as an actual flight item, it has size, shape, and features representative of a typical high-performance fighter aircraft windshield. The purpose of the CFT is to confirm the ADP design capability by molding and testing the CFT, and comparing molding and test results with ADP predictions. Adjustments to variables of the ADP (i.e., material model parameters, modeling techniques, assumptions, etc.) will be considered based on the differences between predicted and actual results.

2.1.1.3 Previous Molding at Envirotech

In January, 1990, WL/FIVR participated in further molding sessions at Envirotech with the prime contractor of the FTP, General Dynamics (now Lockheed Fort Worth Company, LFWC). The objective of the molding trials and subsequent testing was to explore the feasibility of attaching frameless transparencies to aircraft. The approach included molding several insert configurations into the thickened edges of panels (Figure 4). The inserts provided a small cavity which housed a pin such that a hook could latch onto the pin (Figure 5). This arrangement allowed for simulation of latching a frameless transparency to an aircraft interface using molded-in latching inserts.

The 1990 molding sessions were successful, producing 68 flat panels with a nominal thickness of 1/2 inch in the optical area. Most of the panels molded had at least one

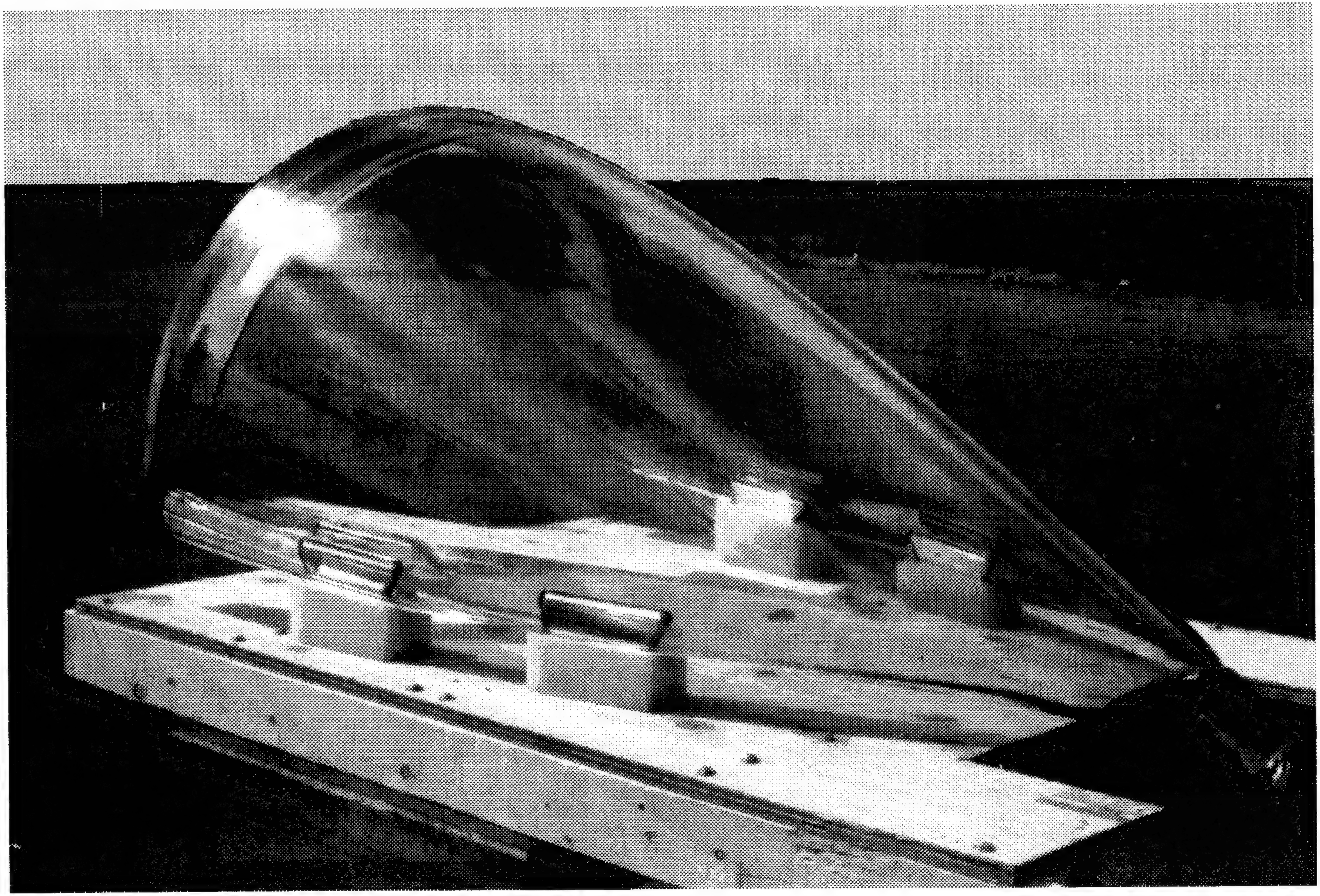


Figure 3. Confirmation Frameless Transparency (CFT)

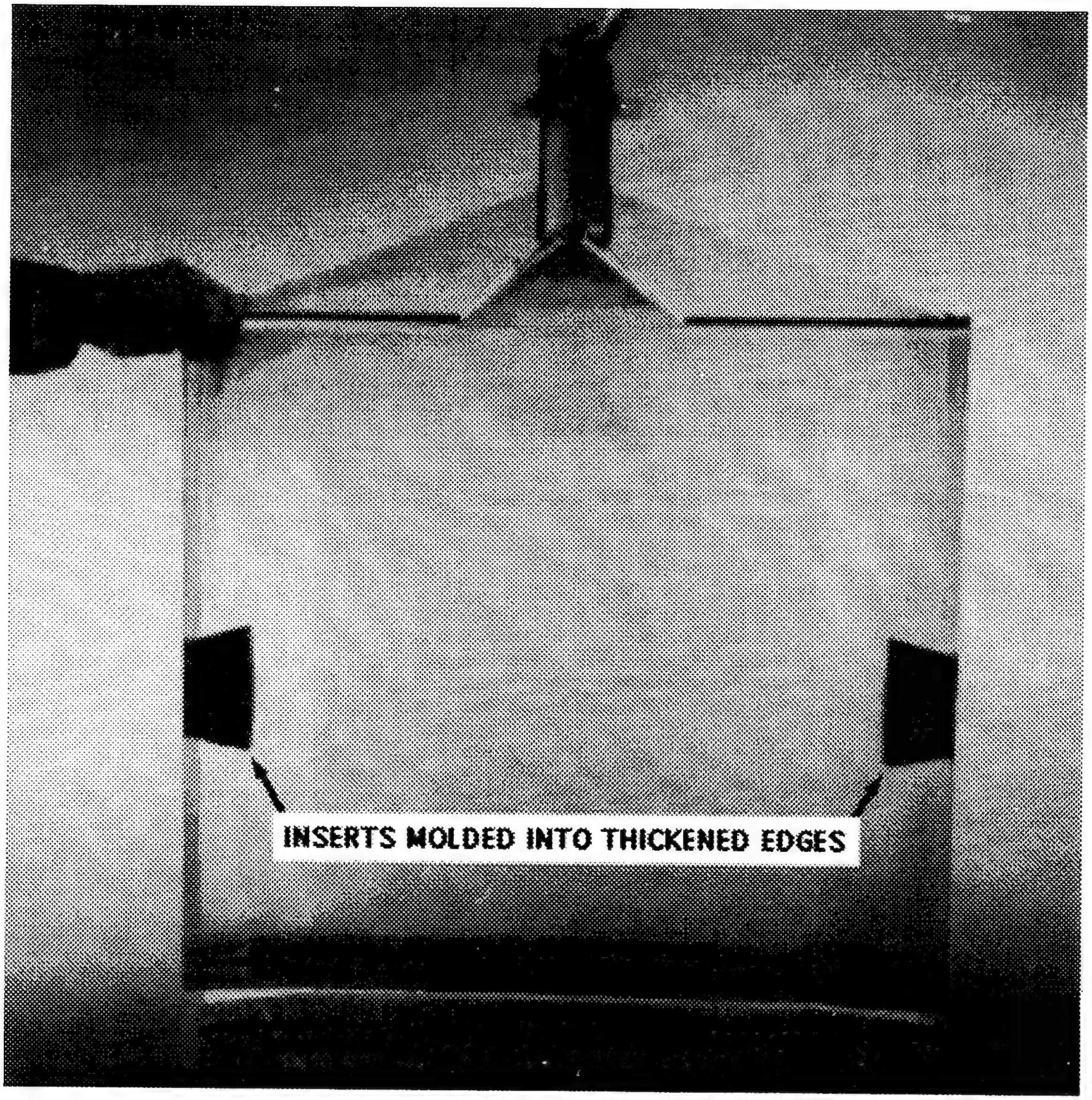


Figure 4. Flat Panel With Molded-In Inserts

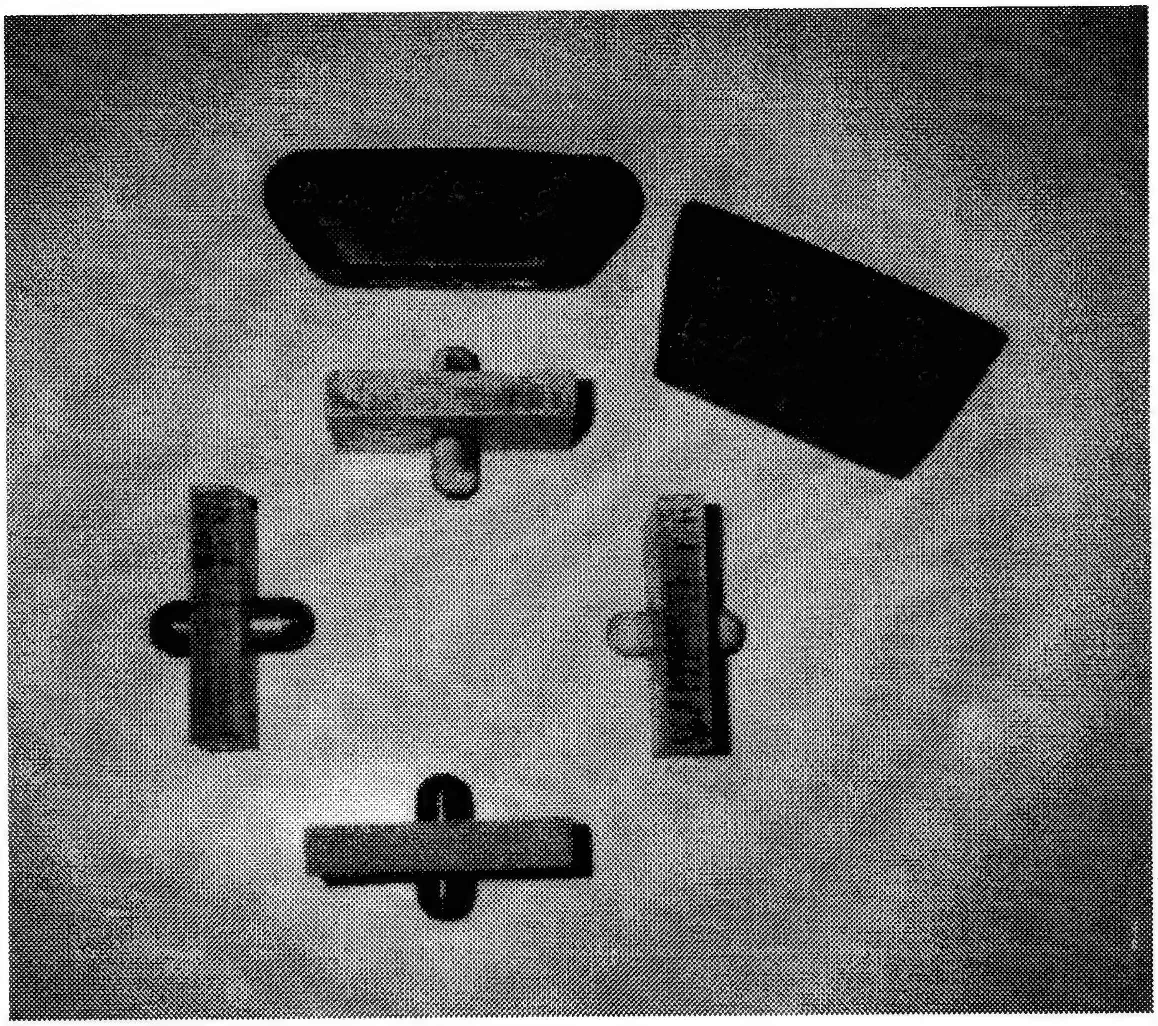


Figure 5. Insert Configurations - January 1990 Molding Trials

of six insert configurations molded in place in the thickened edges. The potential of the insert concept to carry latching loads was confirmed. Testing of the panels and inserts was accomplished by the University of Dayton Research Institute (UDRI), and the test results are documented in References 2 and 3.

2.1.1.4 Previous Molding at Hettinga

WL/FIVR, ALCOA, and UDRI molded 105 flat panels (1/2 inch thick) at Hettinga Equipment Corporation, Des Moine, Iowa, in October, 1990, and January, 1991. The objectives of these molding trials were to explore the feasibility of using thermoplastic inserts (also molded at Hettinga) and to demonstrate successful panel molding utilizing a different type of molding machine.

After some initial difficulties in molding machine setup, panels were again successfully molded. Thermoplastic inserts were molded into the panels, but the resultant interface between insert and panel was not as desirable as using metal inserts. Glass fiber-filled polycarbonate inserts began to remelt from the heat of the molten panel resin. Again, UDRI performed the testing on the inserts and molded panels, and the testing results are documented in References 2 and 3.

2.1.2 Current Molding Effort

By October, 1991, the FTP had progressed to the point where identification of the polycarbonate resin for CFT molding was necessary. Although a family of resins had been chosen (Dow Calibre 300), the choice of resin melt flow index (MFI) was not obvious.

The melt flow index (MFI) of Dow Calibre resins is indicated by the last number in the resin name. For example, the resin Dow 300-15 has an MFI of 15. The MFI is an indicator of how easily the molten resin flows. However, in typical injection molding processes the MFI is also related to impact resistance. As the MFI increases, the molecular weight of the resin decreases, the impact resistance decreases, the viscosity of the molten resin decreases, and

the resin flows more easily into a mold. In some applications a compromise between impact resistance and mold-filling capability may have to be made. A motivation for the subject molding effort was to determine the extent and validity of these relationships for low pressure, long process molding of thick-walled parts.

All previous molding efforts produced either flat or conical panels, 1/2 inch in nominal thickness. The nominal thickness for the CFT was 3/4 inch. Before expending resources to fabricate the CFT mold, the effects of MFI and increased thickness on molding process, shrinkage, impact resistance, and panel quality needed to be investigated. This effort was launched as a molding and testing study to generate input for CFT mold design and CFT molding (Figure 1).

The intent of the molding trials performed in April, 1992, was to mold and evaluate all panels from four different melt flow indexes of the same class of resin, Dow Calibre 300. The actual resins used were: Dow 300-4, Dow 300-6, Dow 300-15, and an experimental resin, Dow XU73093.00L-5.5. A 1/4-inch shim was fabricated for attachment to the existing 1/2-inch flat plate mold, allowing 3/4-inch panels to be molded for the first time. The panels molded under this effort can be categorized into 12 different groups; 3/4-inch thick flat panels from each of the 4 resins, 1/2-inch thick flat panels from each of the 4 resins, and 1/2-inch thick conical panels from each of the 4 resins.

2.1.3 Objectives

The objectives specific to the molding portion of this effort were:

a) Successfully injection mold 3/4-inch flat panels, 1/2-inch flat panels, and 1/2-inch conical panels for subsequent material property testing using Dow Calibre polycarbonate resins formulated for four different melt flow indexes (MFIs).
b) Determine the effects of different melt flow indexes on:
    - molding process
    - quality of the molded panels
    - dimensional variance of panels (i.e., the shrinkage)

- impact resistance of panels

c) Determine the effects of increased thickness (3/4-inch vs. 1/2-inch flat panels) on:

   - molding process
   - quality of the molded panels
   - dimensional variance of panels (i.e., the shrinkage)
   - impact resistance of panels

d) Gain experience and knowledge in the use of the LabVIEW data acquisition system prior to CFT molding.

2.1.4 Scope

The scope of the molding portion of this effort was limited to molding between six and eight panels from each of three panel configurations using each of four resins. A total of 94 panels was produced. On-site evaluation of each panel was accomplished, limited drop dart coupon thickness measurements were obtained, and drop dart tests were performed.

2.1.5 Approach

A 1/4-inch shim kit was fabricated for the 1/2-inch flat plate mold to facilitate molding 3/4-inch panels in addition to the 1/2-inch panels. Also, 1/2-inch conical panels were molded. The panels were then evaluated for relative quality in approximately 20 categories, and numeric values (1-10) were assigned to each panel. Evaluation techniques used in previous USAF panel molding efforts were used; no new techniques were developed. Drop dart coupons were cut from a limited number of flat panels, micrometer thickness measurements were obtained on the coupons, and on-site drop dart testing was accomplished to obtain real time qualitative (pass/fail) impact resistance results. The drop dart testing was done with a simple noninstrumented 20-60 pound dart which fell from a maximum height of 20 feet. The LabVIEW data acquisition system was set up to gain familiarity with the system and to acquire simple mold temperature data.

2.2 1992 Molding Sessions

The molding was accomplished between April 12-23, 1992, at Envirotech Molded Products, Salt Lake City, Utah. Envirotech is a bulk injection molding vendor specializing in large thick-walled parts such as pipeline sections, mining filters, and pump housings. Bulk injection molding is used to produce larger parts at lower pressures (approximately 1000 psi), than typical injection molding (pressures can exceed 20,000 psi). As mentioned in paragraphs 2.1.1.1 and 2.1.1.3, Envirotech has molded hundreds of transparent panels for WL/FIVR in previous molding efforts. In addition to Envirotech personnel, two USAF engineers and one LFWC engineer participated in the molding trials.

The resins used in the molding sessions were Dow Calibre 300-4, Dow Calibre 300-6, Dow Calibre 300-15, and an experimental resin, Dow XU73093.00L-5.5 (also referred to as Dow XU7-5.5). The Calibre resin formulations differed only in MFI, and none of the resins contained coloring dye, mold release, or ultraviolet protection. One thousand pounds each of the Dow Calibre resins were purchased for this effort, and Dow contributed 1000 pounds of the Dow XU7-5.5 resin.

2.2.1 Molding Facilities

The molding facilities and procedures used at Envirotech are proprietary and, as such, will not be discussed in detail in this report. However, general descriptions of the molding equipment, procedures, and molding data will be presented.

2.2.1.1 Injection Molding Machine

The molding machine used in this effort was a two-stage injection molding machine (Figure 6). The first stage consists of a screw (extrusion device) which rotates inside of a heated barrel. The heat from the rotation and heaters combine to plasticize, or melt, the resin. Typical processing temperature was in the 540-570°F range.

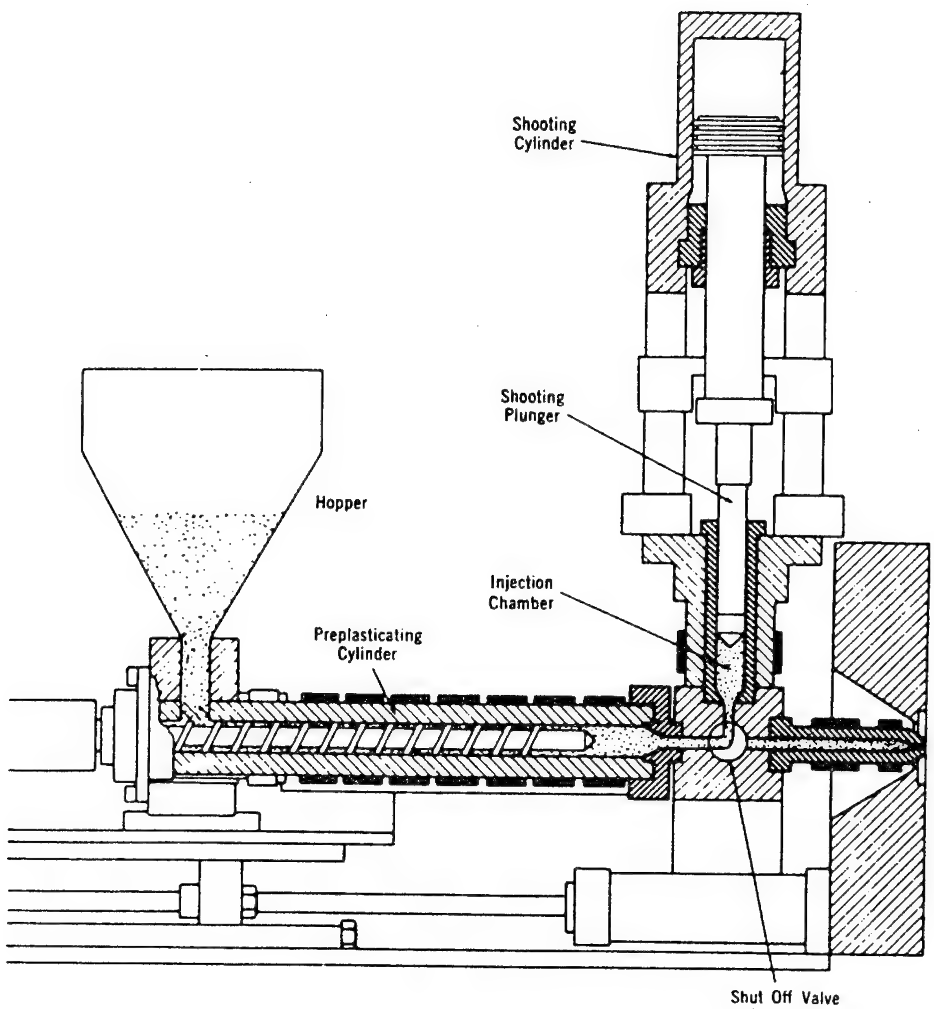


Figure 6. Injection Molding Machine Schematic - Two Stage.

As the screw rotates, plasticized resin is extruded into the second stage, the accumulator. The accumulator is heated and serves as a holding, measuring, and injection unit. The accumulator contains a hydraulic piston which is pushed up by the plasticized resin as the resin fills the accumulator. When the desired amount of resin has been extruded into the accumulator, valve(s) are repositioned and the hydraulic piston pushes the molten resin into the mold. The pressures involved in the panel molding were on the order of 750 psi. The schematic shown in Figure 6 is representative of the major components of a typical injection molding machine.

One of the characteristics of this machine configuration is that the first resin plasticized and extruded into the accumulator is the last resin out of the accumulator (i.e., First In Last Out, FILO). Additionally, a valve mechanism is required to redirect the resin flow, and the resin itself undergoes a reversal of flow. In the FILO configuration of resin flow, there is a chance that a small amount of molten resin may never be forced from areas of the accumulator or associated valving. Therefore, a small amount of resin may remain at the processing temperature over more than one molding cycle. These characteristics have implications on the "melt residency time."

Melt residency time is the length of time the resin has been at its melt temperature. Experience gained in this effort and previous panel molding efforts suggests that the Dow polycarbonate resins used have a useful melt residency time of approximately 20-30 minutes. When the melt residency time exceeds this limit, degradation of the resin can occur. Some effects of resin degradation are: a darkened overall resin color, embrittlement of the molded part, and carbonized or burned specks or chunks embedded in the molded part.

The molding process used in this effort was developed in previous efforts and underwent some minor refinements during this molding trial. Under normal operating conditions the process used was adequate to mold acceptable panels. Melt residency time was kept below the limits stated above, and the overall cycle time was on the order of 30-45 minutes. Over time, though, the number of small black specks in the molded panels sometimes increased, suggesting a slight contamination of "good" resin with degraded resin from within the

accumulator or associated valves. Overall, this minor contamination influenced the aesthetics of the panel rather than the performance or quality.

With the FILO arrangement of resin flow and considering the amount of time it takes to extrude the required amount of resin, the melt residency time of the first portion of resin extruded approaches the time limit beyond which the resin may start to degrade. As stated above, under normal operating conditions the time limit is not exceeded. However, the probability of exceeding the limit goes up dramatically if an unforeseen incident occurs, such as equipment breakdown, a stuck valve, or some other delay. In the harsh environment of injection molding, some of these delays occur quite regularly.

2.2.1.2 Mold Press

The Envirotech molding machine injected molten resin into a mold which was clamped in a large press. The press consisted of two platens, or thick steel plates, configured parallel to each other and parallel to the floor. The top platen remained in a fixed position, integral to the framework of the press. The bottom platen moved relative to the top platen, retracting below the floor to open, or moving up away from the floor to close. The capacity of the press was a maximum of 1500 tons. The capacity needed for the panel molding was on the order of 300 tons.

2.2.1.3 Conical Panel Mold

The conical panel mold (cone mold) was designed and fabricated during the Loral effort in 1986. The mold consisted of a cavity half and a core half (Figure 7), each fabricated from several billets of aluminum. The billets were bolted and welded together, then machined to the desired dimensions. Unfortunately, the seams between billets on the optical surfaces were ground, filled with weld material, and resurfaced. This resulted in a series of three bands of uneven mold surface, and, hence, three bands of optical distortion in every conical panel. Also prior to these molding trials, the core half of the mold had been scratched in transport.

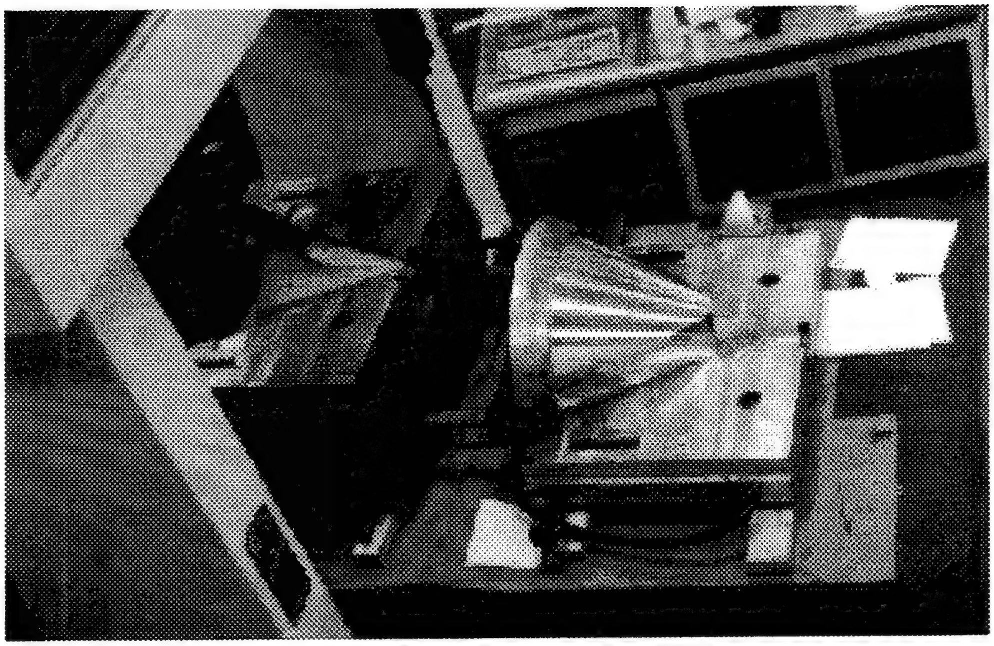


Figure 7. Cone Mold.

An arrangement of 3/4-inch O.D. cooling lines formed a simple six-pass series of coolant flow through each half of the cone mold. The coolant was kept at a nominal temperature of 200°F and simply circulated through the mold halves, taking heat away from the mold as the parts were injected and as the parts cooled. The mold was kept at 200°F prior to the injection of plastic.

In preparation for these molding trials, the cone mold was refurbished. The scratch was removed from the core half, and both halves were polished to restore the original surface finish.

2.2.1.4 Flat Panel Mold

The flat panel mold was also designed and fabricated during the Loral effort in 1986. This mold consisted of a cavity half and a core half (Figure 8), each fabricated from several billets of aluminum. The billets were bolted and welded together, then machined to the desired dimensions. The billets were arranged such that the seams between billets were left as small hairline cracks, or knit-lines, and were not located in the optical surfaces.

An arrangement of 3/4-inch O.D. cooling lines formed a simple eight-pass series of coolant flow through each half of the mold. The coolant was kept at a nominal temperature of 200°F and simply circulated through the mold halves, taking heat away from the mold as the parts were injected and as the parts cooled. The mold was kept at 200°F prior to the injection of plastic.

In preparation for these molding trials, both halves of the flat panel mold were polished, restoring the original surface finish. Additionally, a shim kit was fabricated which permitted the molding of both 3/4-inch and 1/2-inch thick flat panels.

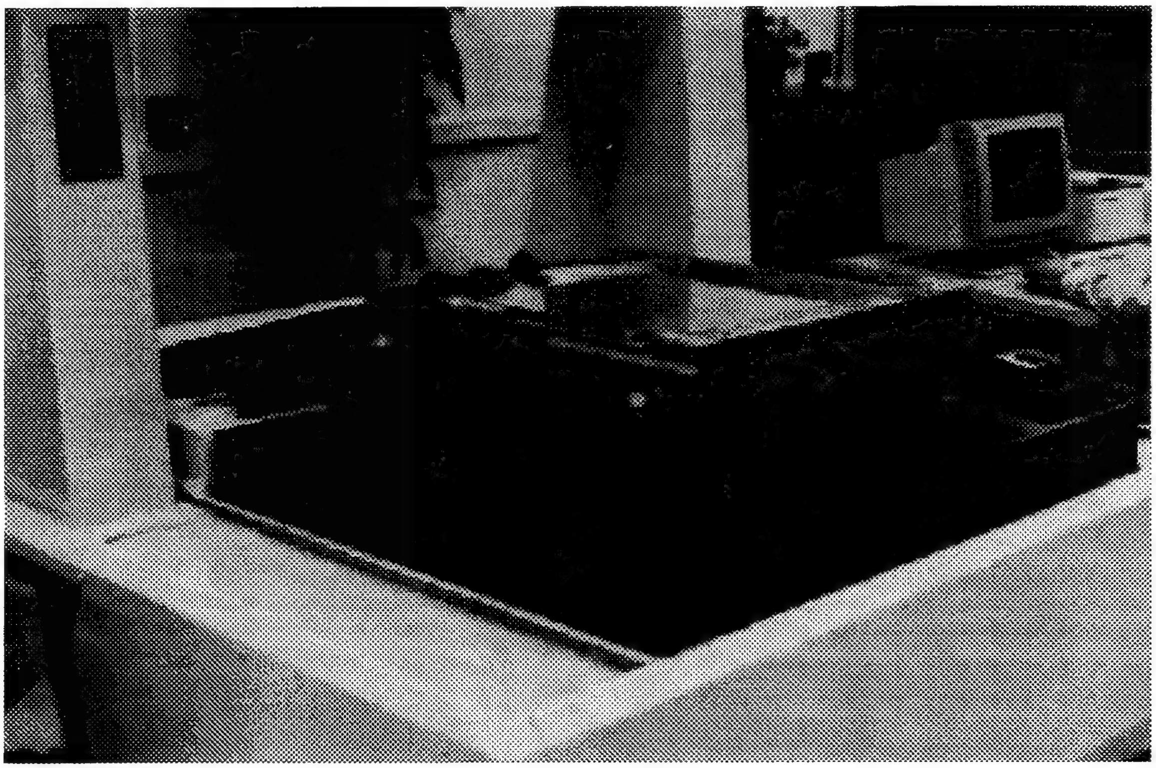


Figure 8. Flat Plate Mold.

2.2.2 Molding

When the USAF and LFWC personnel arrived at Envirotech on April 12, 1993, the molds and resin were in place. The flat plate mold was installed in the press and the first batch of resin (Dow 300-15) was drying. The drop dart apparatus had been installed, and space for panel evaluation was provided. The LFWC engineer was provided space and resources to set up the LabVIEW system at the molding machine site.

2.2.2.1 Molding Panels

As mentioned in the previous paragraph, the resin needs to be dried before molding. Dow recommends the resin be dried for at least 3 hours at 250°F prior to plasticizing. Previous panel molding experience had shown that moisture in the molten resin results in unacceptable parts.

A typical injection molding cycle for the panels lasted between 30 and 45 minutes. The steps in a cycle were:

1) Injection - Resin was injected into the mold at approximately 750 psi. The injection duration lasted between 7-15 seconds.
2) Packing - Packing began at the end of injection. Packing is the process of forcing molten resin into the mold under a predetermined packing pressure as the part cools. Reduction of volume as the resin cools results in shrinkage from mold walls if additional resin does not enter the mold cavity. The part eventually solidifies (freezes), and no more material can be forced into the mold. Packing generally lasted for about 30 minutes in this panel molding.
3) Cooling - Cooling is the process which reduces the temperature to a level which permits removal of the part from the mold. Cooling is typically accomplished by coolant flowing through lines in the mold. As the coolant circulates, heat is carried away from the mold. Although the cooling cycle is generally considered to begin after pressure has been removed (at the end of packing), cooling was done during the packing cycle for this molding trial.

The order in which panels were molded was chosen to minimize the downtime between the molding of different panel configurations. Changing resins involved purging the drier, hopper, and molding machine of the previous resin. Then the new resin had to be dried before molding could begin again. Installing or removing the 1/4-inch shim took less time than changing resins. Table 1 summarizes the order of panel molding.

As each panel was extracted from the mold, it was labeled with the Process ID and Panel ID number. These two numbers were needed to uniquely identify each panel. The Process ID was an Envirotech number that identified a particular mold/resin combination. The Panel ID number was a date coded number of the form YYMMDD-nn, where nn started at 01 with the first panel of the series and continued until the mold/resin configuration changed.

During the flat plate molding at least one short shot was molded from each of the eight groups of panels. A short shot is an injection of a fraction of the panel volume (Figure 9). The purpose of a short shot is to view the flow front pattern when the mold is partially filled. This pattern can be compared with analytical predictions of the flow front for the time associated with the end of injection of the short shot volume.

During the conical panel molding the first cone in three of the four groups was intentionally not packed. The objective of this was to determine the implications of not packing a part. Although it was known that improper packing would result in unacceptable parts, a quantification of the effects was desired. The unpacked cones would be dimensionally mapped along with some packed cones later in the testing portion of this effort.

2.2.2.2 Data Acquisition - Process Sheets

It was necessary that all information pertinent to the molding be documented. In general terms this information included: date and time of molding events, temperatures, pressures, elapsed times, names of relevant personnel, and appropriate comments on all phases of the panel molding sessions.

Table 1. April 1992 Molded Panel Summary.

Flat Panel Summary					
Molding Order	Process ID	Material	Thickness	Envirotech Material ID	Panel ID Numbers
1	MX2049	DOW 300-15	0.75"	ZA05N0	920413-01 thru 10
2	MX2053	DOW 300-15	0.50"	ZA05N0	920414-01 thru 08
3	MX2052	DOW 300-6	0.50"	ZA06N0	920414-01 thru 08
4	MX2048	DOW 300-6	0.75"	ZA06N0	920414-01 thru 08
5	MX2050	DOW XU7-5.5	0.75"	ZA09N0	920415-01 thru 08
6	MX2054	DOW XU7-5.5	0.50"	ZA09N0	920415-01 thru 08
7	MX2051	DOW 300-4	0.50"	ZA04N0	920415-01 thru 08
8	MX2047	DOW 300-4	0.75"	ZA04N0	920416-01 thru 09
Conical Panel Summary					
Molding Order	Process ID	Material	Thickness	Envirotech Material ID	Panel ID Numbers
9	MX2057	DOW 300-15	0.50"	ZA05N0	920421-01 thru 07
10	MX2056	DOW 300-6	0.50"	ZA06N0	920421-01 thru 07
11	MX2058	DOW XU7-5.5	0.50"	ZA09N0	920421-01 thru 06 and 920422-07
12	MX2055	DOW 300-4	0.50"	ZA04N0	920422-01 thru 06

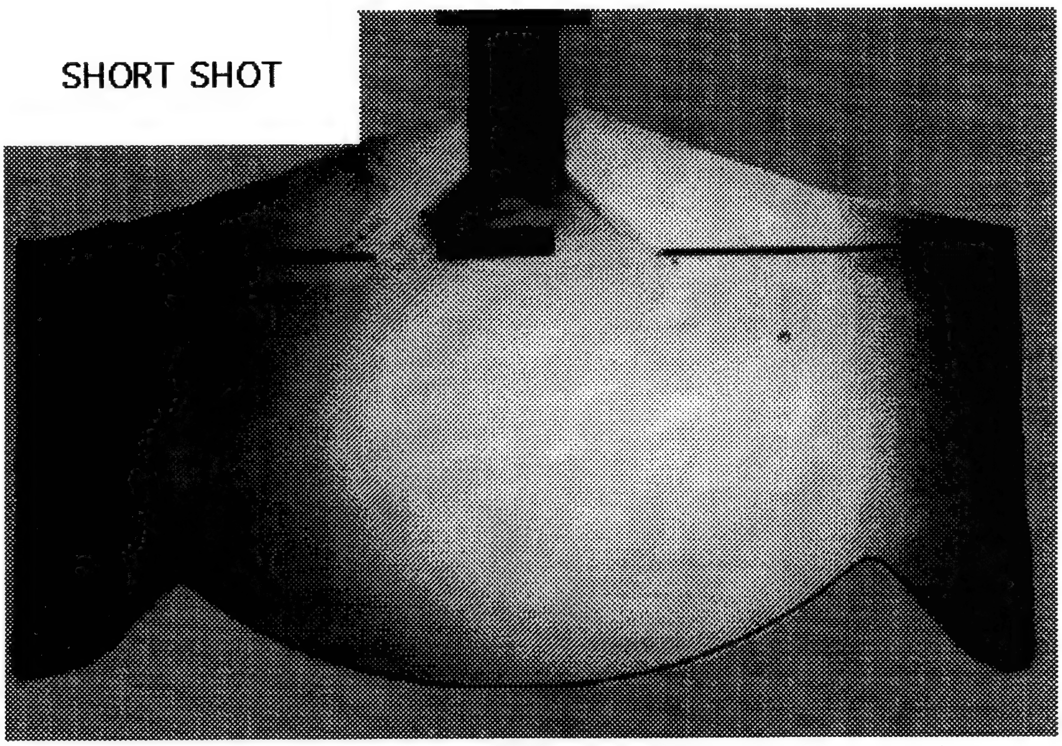


Figure 9. Example of Flat Panel Short Shot

Envirotech molding personnel filled out molding process sheets for each panel. As necessary, USAF personnel recorded data on the process sheets as well. The process sheets had descriptive data about the panel and the machine setup and formed a paper record of the molding trials. An Envirotech process sheet is shown in Figure 10, and some of the terms on the process sheet are explained on the following pages (the entry headings are underlined). Pertinent information from process sheets for each molded panel is summarized in the upper rows of Table 2, identified as "Molding Parameters."

PART NO. - The number used by Envirotech to describe a mold/material combination is entered here. WL/FIVR has called this the Process ID. This number must be used in conjunction with the date code to uniquely describe a part. Typically, this number begins with "MX." A typical entry is "MX2049," which is the process ID of a 3/4-inch Flat Panel part made from Dow 300-15 resin.

PART NAME - A text description of the part is entered here. A typical entry is "3/4-Inch Flat Panel."

CUSTOMER - An identification of the organization for which Envirotech is molding is entered here.

S.O. NO. - An Envirotech internal number is entered here.

RESIN TYPE - A short description of the resin is entered here. It is desirable to have the resin manufacturer, resin type, and melt flow index here. A typical entry is "Dow 300-4."

LOT NO. - The resin has a lot number associated with it. The lot number is entered here.

MOLDER - The mold operator puts his initials in this space.

SHIFT - The mold operator enters his shift here. Envirotech ran 24 hours a day during the molding in April, 1992. There were four shifts: A, B, C, and D. Each shift was 12 hours long.

ENVIROTECH PROCESS SHEET

PART NO. __________ PART NAME ______________________ CUSTOMER __________________

S.O. NO. _______________ RESIN TYPE ____________ LOT NO. _______________________

MOLDER __________ SHIFT __________ MACH NO. _______

DATE CODE ___________ SHOT TIME ____________ REMOVE TIME ____________

MOLD TEMP. TOP ________ BOTTOM ________

MELT TEMP. __________

INJECTION PRESSURE ____________

INJECTION SPEED SETTING ________________ FILL TIME (SECONDS) ______________

PACK PRESSURE ____________

PACK TIME __________ ACTUAL _____________________

DRYER CONDITIONS: TEMPERATURE ________ TIME ________

NOTE: RECORD ALL TIMES TO NEAREST MINUTE AND PRESSURES AS ACCURATELY AS CAN BE DETERMINED FROM GAUGE.

MACHINE CONDITIONS

	SET POINT (deg. F.)	ACTUAL		SET POINT (deg. F.)	ACTUAL
ZONE 1			ZONE 2		
ZONE 3			ZONE 4		
DIE ZONE			HEAD ZONE		
VALVE			GUN TOP		
GUN BOTTOM			NOZZLE TUBE		
NOZZLE TIP					

SCREW SPEED ____________RPM

REMARKS: ____

____

Figure 10. Envirotech Process Sheet.

Table 2. Molding Process and Panel Evaluation Summary

S-92 Molding, Envirotech,										
Salt Lake, UT April 1992	*	~~~~~~~~~~~~	~~~~~~~~~~~~	FIVR 3/4 in FLAT PANELS		~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~
see note for cell A3	*									
RESIN TYPE	*	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15
RESIN TYPE & PANEL TYPE	*	Dow 300-15 Flat -	Dow 300-15 Flat -	Dow 300-15 Flat -	Dow 300-15 Flat -	Dow 300-15 Flat -	Dow 300-15 Flat -	Dow 300-15 Flat -	Dow 300-15 Flat -	Dow 300-15 Flat -
PROCESS NUMBER	*	MX2049	MX2049	MX2049	MX2049	MX2049	MX2049	MX2049	MX2049	MX2049
PANEL I.D. (YYMMDD-##)	*	920413-01	920413-02	920413-03	920413-04	920413-05	920413-06	920413-07	920413-08	920413-09
PANEL TYPE	*	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in
**	*	****************	****************	****************	****************	****************	****************	****************	****************	****************
MOLDING PARAMETERS:										
RESIN DRY TIME (HRS)	*									
ACCUMULATE TIME (min)	*	22.00	22.00	22.00	22.00	22.00	26.00	26.00	26.00	26.00
ACCUMULATE QUANTITY (piston pos inches)	*	11.00	11.00	11.00	11.00	11.00	13.00	13.00	13.00	13.00
ACCUMULATOR PURGE (before/after fill)	*									
TOD - NOZZLE IN; VALVE ROTATION	*	13:40	15:00	16:00	17:10	18:10	19:12	22:20	23:20	0:20
FILLING TIME (seconds)	*	10.30		7.50	10.96	8.31	9.42	7.53	7.50	7.50
INJECT PRESSURE MAX (psi)	*	750	750	750	750	750	750	750	750	750
PACKING PRESSURE (psi)	*	750	750	750	750	750	750	750	750	750
TOD - MOLD OPEN	*	14:45	15:45	16:45	17:55	18:55	19:57	23:05	00:05	01:05
MOLD TEMP DATA FILE (Y/N)	*									
MOLD CAV TEMP; FILL (deg F)	*	197	205	206	205	210	211	204	210	214
MOLD CORE TEMP; FILL (deg F)	*	194	205	207	207	212	213	204	212	217
MELT TEMP; NOZZLE TIP; FILL (deg F)	*	572	572	572	572	573	573	573	573	573
SCREW RPM	*	50	50	50	50	50	50	50	50	50
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.	*	purge before fill had streaks and gel; this full shot considered preliminary	Short Shot about 90%; tried 40%	No packing nozzle leak; valve off at end of fill; use this panel to judge effect of packing	purge before fill still has streaks and gel	unknown pack valve closed accidentally some time after fill	bigger accu volume for more purge; no manual purge cutoff before nozzle in	improved purge; time delay due to change in accu hyd cylinder		
**	*	****************	****************	****************	****************	****************	****************	****************	****************	****************
MOLDED PANEL CHARACTERISTICS:	*	3/4; 15 MFI	3/4; 15 MFI	3/4; 15 MFI	3/4; 15 MFI	3/4; 15 MFI	3/4; 15 MFI	3/4; 15 MFI	3/4; 15 MFI	3/4; 15 MFI
(eval code 1 good; 10 bad)	*									
WEIGHT (pounds)	*	29.63	24.06	28.36	29.55	29.63	29.58	29.63	29.63	29.63
OVERALL QUALITY	*	9	10	9	7	7	8	5	3	4
SURFACE SPLAY; STREAKING	*	9	9	8	7	6	4	5	2	3
THICKENED EDGE SINK	*	2		4	3	6	3	2	2	2
BUBBLES	*	8	10	9	5	8	5	7	4	1
VOIDS	*	1		1	1	1	1	1	1	1
ORANGE PEEL	*	3		5		3	6	4	1	3
DARK STREAKS	*	2	1	3	2	4	9	3	3	4
DARK SPECKS DEBRIS	*	1	1	1	1	1	1	3	2	8
WELD LINE INTENSITY; DEPTH	*	9		7	5	7	1	1	1	1
BEST COLOR	*	WW	ww	ww	ww	ww	ww	ww	ww	ww
WELD LINE JUNCTURE TO EDGE (inches)	*	off panel	n/a	off panel	offpanel	off panel	off panel	off panel	off panel	off panel
WELD LINE JUNCT OFF CL (inches)	*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WELD LINE JUNCT DEPTH (inches)	*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Oil Craze 1-10 (edges)	*						8.00	8.00		
Oil Craze arch	*									
Oil Craze Const. Thickness Area	*									
Oil Craze sills	*									
DART TEST COUPONS (abc;d)	*	n/a	n/a	a;b;c;d	a;b;c;d	n/a	a;b;c;d	a;b;c;d		
	*									
EVALUATION COMMENTS:	*		bubbles all over normal looking shape	bubbles in all thickened edges small bubbles also in const thick	bubbles fewer and one sill edge only	bubbles may be due to short pack	Large dark streak with very degraded material 1/3 of panel	Rows of bubbles down sills	Best of 3/4" -15 panels	
date code ==> yymmdd-panel number										
no inserts										
mold core - concve side of panels										
port side ==> left side when facing gate end from trailing edge with concave face up										
short shot ==> intentional injection of less material than required to fill mold										
units:										
temperatures - deg F										
length or distance - inches										
time - seconds (unless minutes indicated)										
pressure - psi										

Table 2. Molding Process and Panel Evaluation Summary (continued)

S-92 Molding, Envirotech; Salt Lake, UT April 1992									
see note for cell A3	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	FIVR 1/2 in FLAT PANELS		~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~
RESIN TYPE	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15
RESIN TYPE & PANEL TYPE	Dow 300-15 Flat -	Dow 300-15 Flat	Dow 300-15 Flat -	Dow 300-15 Flat -	Dow 300-15 Flat -	Dow 300-15 Flat -	Dow 300-15 Flat -	Dow 300-15 Flat -	Dow 300-15 Flat -
PROCESS NUMBER	MX2049	MX2053	MX2053	MX2053	MX2053	MX2053	MX2053	MX2053	MX2053
PANEL I.D. (YYMMDD-##)	920413-10	920414-01	920414-02	920414-03	920414-04	920414-05	920414-06	920414-07	920414-09
PANEL TYPE	Flat - 3/4 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in
**	************	****************	****************	****************	****************	****************	****************	****************	****************
MOLDING PARAMETERS:									
RESIN DRY TIME (HRS)									
ACCUMULATE TIME (min)	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
ACCUMULATE QUANTITY (piston pos inches)	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00
ACCUMULATOR PURGE (before/after fill)									
TOD - NOZZLE IN; VALVE ROTATION	1:20	6:30	7:05	7:55	9:15	10:40	11:25	12:15	13:00
FILLING TIME (seconds)	7.98		8.00	7.78	7.00	7.90	7.30	8.90	8.50
INJECT PRESSURE MAX (psi)	750	750	750	750	750	750	750	750	750
PACKING PRESSURE (psi)	750	750	750	750	750	750	750	750	750
TOD - MOLD OPEN	02:05	07:00	07:35	08:25	09:45	11:10	11:55	12:45	13:30
MOLD TEMP DATA FILE (Y/N)		NO	NO	NO	NO	NO	NO	NO	NO
MOLD CAV TEMP; FILL (deg F)	216	180	200	203	209	202	208	210	211
MOLD CORE TEMP; FILL (deg F)	217	182	204	208	201	205	212	213	215
MELT TEMP; NOZZLE TIP; FILL (deg F)	573	554	555	550	550	544	560	560	560
SCREW RPM	50	50	50	50	50	50	50	50	50
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.									
**	************	*************	*************	*************	*************	*************	*************	*************	*************
MOLDED PANEL CHARACTERISTICS:	3/4; 15 MFI	1/2; 15 MFI	1/2; 15 MFI	1/2; 15 MFI	1/2; 15 MFI	1/2; 15 MFI	1/2; 15 MFI	1/2; 15 MFI	1/2; 15 MFI
(eval code 1 good; 10 bad)									
WEIGHT (pounds)	29.63	18.63	22.75	22.69	22.75	22.69	22.69	22.69	22.75
OVERALL QUALITY	6	10	5	5	6	5	2	2	2
SURFACE SPLAY; STREAKING	5	6	6	4	6	5	1	2	1
THICKENED EDGE SINK	2		5	5	3	4	7	4	2
BUBBLES	1	2	2	1	3	2	1	2	4
VOIDS	1		1	1	1	1	1	1	1
ORANGE PEEL	4	4	2	5	1	3	3	3	3
DARK STREAKS	5	1	2	6	2	6	5	4	5
DARK SPECKS DEBRIS	7	3	6	7	2	6	8	3	2
WELD LINE INTENSITY; DEPTH	3		3	4	1	3	3	1	2
BEST COLOR	WW	WW	WW	WW	WW	WW	WW	WW	WW
WELD LINE JUNCTURE TO EDGE (inches)	off panel	SS	0.63	0.63	0.63	0.55	0.75	0.75	0.81
WELD LINE JUNCT OFF CL (inches)	n/a	SS	0.31	0.16	0.19	0.13	0.19	0.13	0.50
WELD LINE JUNCT DEPTH (inches)	n/a	SS	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE	surface	SURFACE
Oil Craze 1-10 (edges)									
Oil Craze arch									
Oil Craze Const. Thickness Area									
Oil Craze sills									
DART TEST COUPONS (abc;d)		N/A	N/A	A;B;C;D	N/A	N/A	N/A	A;B;C;D	N/A
EVALUATION COMMENTS:		SHORT SHOT					MAPPING; BI TEST		MAPPING; BI TEST
date code ==> yymmdd-panel number									
no inserts									
mold core - concve side of panels									
port side ==> left side when facing gate end fro									
short shot ==> intentional injection of less mat									
units:									
temperatures - deg F									
length or distance - inches									
time - seconds (unless minutes indicated)									
pressure - psi									

Table 2. Molding Process and Panel Evaluation Summary (continued)

S-92 Molding, Envirotech,									*	
Salt Lake, UT April 1992	~~~~~~~~~~~~	~~~~~~~~~~~~	PIVR 1/2 in FLAT PANELS		~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	*	~~~~~~~~~~~~
see note for cell A3									*	
RESIN TYPE	Dow 300-6	Dow 300-6	Dow 300-6	Dow 300-6	Dow 300-6	Dow 300-6	Dow 300-6	Dow 300-6	*	Dow 300-6
RESIN TYPE & PANEL TYPE	Dow 300-6 Flat -	Dow 300-6 Flat -	Dow 300-6 Flat -	Dow 300-6 Flat -	Dow 300-6 Flat -	Dow 300-6 Flat -	Dow 300-6 Flat -	Dow 300-6 Flat -	*	Dow 300-6 Flat -
PROCESS NUMBER	MX2052	MX2052	MX2052	MX2052	MX2052	MX2052	MX2052	MX2052	*	MX2048
PANEL I.D. (YYMMDD-##)	920414-01	920414-02	920414-03	920414-04	920414-05	920414-06	920414-07	920414-08	*	920414-01
PANEL TYPE	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	*	Flat - 3/4 in
************************************	*************	*************	*************	*************	*************	*************	*************	*************	*	*************
MOLDING PARAMETERS:										
RESIN DRY TIME (HRS)									*	
ACCUMULATE TIME (min)		14.00							*	26.00
ACCUMULATE QUANTITY (piston pos inches)		7.75							*	13.00
ACCUMULATOR PURGE (before/after fill)									*	b
TOD - NOZZLE IN; VALVE ROTATION	15:25	16:10	17:00	17:40	18:30	19:15	20:00	20:40	*	22:40
FILLING TIME (seconds)	12.3	11.7	11.9	11.9	12.12	11.67	12.44	12.7	*	5.19
INJECT PRESSURE MAX (psi)	750	750	750	750	750	750	750	750	*	750
PACKING PRESSURE (psi)	750	750	750	750	750	750	750	750	*	750
TOD - MOLD OPEN	15:55	16:40	17:30	18:10	19:00	10:48	20:30	21:10	*	23:25
MOLD TEMP DATA FILE (Y/N)									*	N
MOLD CAV TEMP; FILL (deg F)	204	211	213	216	213	216	214	215	*	
MOLD CORE TEMP; FILL (deg F)	208	216	215	220	216	220	218	220	*	
MELT TEMP; NOZZLE TIP; FILL (deg F)	560	560	559	560	560	560	560	560	*	560
SCREW RPM	40	40	40	40	40	40	40	40	*	40
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.	short shot								*	SHORT SHOT
************************************	*************	*************	*************	*************	*************	*************	*************	*************	*	*************
MOLDED PANEL CHARACTERISTICS:	1/2; 6 MFI	1/2; 6 MFI	1/2; 6 MFI	1/2; 6 MFI	1/2; 6 MFI	1/2; 6 MFI	1/2; 6 MFI	1/2; 6 MFI	*	3/4; 6 MFI
(eval code 1 good; 10 bad)									*	
WEIGHT (pounds)	9.78	22.75	22.73	22.75	22.73	22.73	22.73	22.73	*	12.76
OVERALL QUALITY	10	5	7	7	4	7	6	7	*	10
SURFACE SPLAY; STREAKING	5	5	8	7	5	4	3	3	*	
THICKENED EDGE SINK		6	6	7	7	7	7	6	*	
BUBBLES	3	4	4	7	6	9	7	8	*	9
VOIDS		1	1	1	1	1	1	1	*	
ORANGE PEEL	1	2	6	5	4	5	4	3	*	3
DARK STREAKS	2	3	3	1	2	3	2	3	*	5
DARK SPECKS DEBRIS	4	6	1	1	1	1	1	1	*	1
WELD LINE INTENSITY; DEPTH		5	7	7	3	7	5	7	*	
BEST COLOR	WW	WW	WW	WW	WW	WW	WW	WW	*	WW
WELD LINE JUNCTURE TO EDGE (inches)	N/A	0.94	0.94	0.88	0.94	0.94	0.94	0.94	*	SS
WELD LINE JUNCT OFF CL (inches)	N/A	0.19	0.25	0.25	0.13	0.19	0.31	0.31	*	SS
WELD LINE JUNCT DEPTH (inches)	N/A	SURACE	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE	*	SS
Oil Craze 1-10 (edges)									*	
Oil Craze arch									*	
Oil Craze Const. Thickness Area									*	
Oil Craze sills									*	
DART TEST COUPONS (abc;d)	N/A	A;B;C;D	N/A	N/A	N/A	N/A	N/A	A;B;C;D	*	N/A
									*	
EVALUATION COMMENTS:									*	
date code ==> yymmdd-panel number									*	
no inserts									*	
mold core - concve side of panels									*	
port side ==> left side when facing gate end fro									*	
short shot ==> intentional injection of less mat									*	
units:									*	
temperatures - deg F									*	
length or distance - inches									*	
time - seconds (unless minutes indicated)									*	
pressure - psi									*	

Table 2. Molding Process and Panel Evaluation Summary (continued)

8-92 Molding, Envirotech,										
Salt Lake, UT April 1992	~~~~~~~~~~~~	FIVR 3/4 in FLAT PANELS		~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	*	~~~~~~~~~~~~	~~~~~~~~~~~~
see note for cell A3										
RESIN TYPE	Dow 300-6	Dow 300-6	Dow 300-6	Dow 300-6	Dow 300-6	Dow 300-6	Dow 300-6	*	DOW XU73093.00L	DOW XU73093.00L
RESIN TYPE & PANEL TYPE	Dow 300-6 Flat -	Dow 300-6 Flat -	Dow 300-6 Flat -	Dow 300-6 Flat -	Dow 300-6 Flat -	Dow 300-6 Flat -	Dow 300-6 Flat -	*	DOW XU73093.00L F	DOW XU73093.00L F
PROCESS NUMBER	MX2048	MX2048	MX2048	MX2048	MX2048	MX2048	MX2048	*	MX2050	MX2050
PANEL I.D. (YYMMDD-##)	920414-2	920414-03	920414-04	920414-05	920414-06	920414-07	920414-08	*	920415-01	920415-02
PANEL TYPE	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	*	Flat - 3/4 in	Flat - 3/4 in
************************************	****************	****************	****************	****************	****************	****************	****************	*	****************	****************
MOLDING PARAMETERS:										
RESIN DRY TIME (HRS)										
ACCUMULATE TIME (min)	26.00	26.00	26.00	26.00	26.00	26.00	26.00	*		
ACCUMULATE QUANTITY (piston pos inches)	13.00	13.00	13.00	13.00	13.00	13.00	13.00	*	13.00	13.00
ACCUMULATOR PURGE (before/after fill)	b	b	b	b	b	b	b	*		
TOD - NOZZLE IN; VALVE ROTATION	23:35	0:30	1:45	2:40	3:35	4:30	5:25	*	8:35	9:35
FILLING TIME (seconds)	13.08	11.67	12.64	12.84	11.68	12.5	12.08	*		15.1
INJECT PRESSURE MAX (psi)	750	750	750	750	750	750	750	*	750	750
PACKING PRESSURE (psi)	750	750	750	750	750	750	750	*		750
TOD - MOLD OPEN	00:20	01:15	02:30	03:25	04:20	05:15	06:10	*	09:20	10:20
MOLD TEMP DATA FILE (Y/N)	N	N	N	N	N	N	N	*	N	N
MOLD CAV TEMP; FILL (deg F)	204	208	211	210	213	214	213	*	199	203
MOLD CORE TEMP; FILL (deg F)	206	211	215	214	217	219	220	*	201	207
MELT TEMP; NOZZLE TIP; FILL (deg F)	560	560	561	560	560	561	560	*	560	560
SCREW RPM	40	40	40				25	*	30	30
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.	A-D side to FIVR 19May92							*		
************************************	*************	*************	*************	*************	*************	*************	*************	*	*************	*************
MOLDED PANEL CHARACTERISTICS:	3/4; 6 MFI	3/4; 6 MFI	3/4; 6 MFI	3/4; 6 MFI	3/4; 6 MFI	3/4; 6 MFI	3/4; 6 MFI	*	3/4; 5.5 MFI	3/4; 5.5 MFI
(eval code 1 good; 10 bad)								*		
WEIGHT (pounds)	29.63	29.63	29.63	29.56	29.63	29.63	29.56	*	11.94	29.50
OVERALL QUALITY	5	3	6	5	6	5	6	*	10	5
SURFACE SPLAY; STREAKING	6	3	7	5	5	6	2	*	4	7
THICKENED EDGE SINK	3	4	4	3	3	4	4	*		2
BUBBLES	2	2	1	3	5	2	2	*	1	1
VOIDS	1	1	1	1	1	1	1	*		1
ORANGE PEEL	5	2	4	3	6	2	7	*		3
DARK STREAKS	4	3	3	2	3	2	2	*	2	1
DARK SPECKS DEBRIS	3	1	2	2	3	1	6	*	9	4
WELD LINE INTENSITY; DEPTH	2	1	5	2	1	1	1	*		1
BEST COLOR	WW	WW	WW	WW	WW	WW	WW	*	LA	LA
WELD LINE JUNCTURE TO EDGE (inches)	OFF PANEL	OFF PANEL	OFF PANEL	OFF PANEL	OFF PANEL	OFF PANEL	OFF PANEL	*	N/A	OFF PART
WELD LINE JUNCT OFF CL (inches)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	*	N/A	N/A
WELD LINE JUNCT DEPTH (inches)	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE	*	N/A	N/A
Oil Craze 1-10 (edges)								*		
Oil Craze arch								*		
Oil Craze Const. Thickness Area								*		
Oil Craze sills								*		
DART TEST COUPONS (abc;d)	a;b;c;d				a;b;c;d			*	N/A	
EVALUATION COMMENTS:								*	SHORT SHOT LA => light amber	
date code ==> yymmdd-panel number										
no inserts								*		
mold core - concve side of panels								*		
port side ==> left side when facing gate end fro								*		
short shot ==> intentional injection of less mat								*		
units:								*		
temperatures - deg F								*		
length or distance - inches								*		
time - seconds (unless minutes indicated)								*		
pressure - psi								*		

Table 2. Molding Process and Panel Evaluation Summary (continued)

S-92 Molding, Envirotech,							*			
Salt Lake, UT April 1992	FIVR 3/4 in FLAT PANELS		~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	*	~~~~~~~~~~~~	~~~~~~~~~~~~	FIVR 1/2 in FLAT
see note for cell A3							*			
RESIN TYPE	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	*	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L
RESIN TYPE & PANEL TYPE	DOW XU73093.00L F	DOW XU73093.00L F	DOW XU73093.00L F	DOW XU73093.00L F	DOW XU73093.00L F	DOW XU73093.00L F	*	DOW XU73093.00L F	DOW XU73093.00L F	DOW XU73093.00L F
PROCESS NUMBER	MX2050	MX2050	MX2050	MX2050	MX2050	MX2050	*	MX2054	MX2054	MX2054
PANEL I.D. (YYMMDD-##)	920415-03	920415-04	920415-05	920415-06	920415-07	920415-08	*	920415-01	920415-02	920415-03
PANEL TYPE	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	*	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in
**	****************	****************	****************	****************	****************	****************	*	****************	****************	****************
MOLDING PARAMETERS:										
RESIN DRY TIME (HRS)							*			
ACCUMULATE TIME (min)							*			
ACCUMULATE QUANTITY (piston pos inches)	13.00	13.00	13.00	13.00	13.00	13.00	*			
ACCUMULATOR PURGE (before/after fill)							*			
TOD - NOZZLE IN; VALVE ROTATION	10:40	11:45	13:05	14:10	15:25	16:20	*	17:55	18:30	19:15
FILLING TIME (seconds)	14.4	15.8	14.1	14.9	16.9	15.7	*	7.6	14.84	14.67
INJECT PRESSURE MAX (psi)	750	750	750	750	750	750	*	750	750	750
PACKING PRESSURE (psi)	750	750	750	750	750	750	*	750	750	750
TOD - MOLD OPEN	11:25	12:40	12:50	14:55	16:10	17:05	*	18:25	19:00	19:45
MOLD TEMP DATA FILE (Y/N)	N	N	N	N	N	N	*			
MOLD CAV TEMP; FILL (deg F)	206	207	207	207	206	210	*	185	204	210
MOLD CORE TEMP; FILL (deg F)	211	210	211	211	209	212	*	184	209	214
MELT TEMP; NOZZLE TIP; FILL (deg F)	560	560	560	560	560	561	*	560	561	561
SCREW RPM	30	30	30	30	30	30	*	30	30	30
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.							*			
**	*************	*************	*************	*************	*************	*************	*	*************	*************	*************
MOLDED PANEL CHARACTERISTICS:	3/4; 5.5 MPI	3/4; 5.5 MPI	3/4; 5.5 MPI	3/4; 5.5 MPI	3/4; 5.5 MPI	3/4; 5.5 MPI	*	1/2; 5.5 MPI	1/2; 5.5 MPI	1/2; 5.5 MPI
(eval code 1 good; 10 bad)							*			
WEIGHT (pounds)	29.56	29.63	29.56	29.56	29.63	29.56	*	6.56	22.63	22.69
OVERALL QUALITY	4	3	4	4	3	5	*	10	5	3
SURFACE SPLAY; STREAKING	2	5	5	5	5	7	*	3	1	1
THICKENED EDGE SINK	2	3	3	3	4	5	*		5	4
BUBBLES	2	2	1	2	1	2	*	2	1	2
VOIDS	1	1	1	1	1	1	*		1	1
ORANGE PEEL	6	3	6	4	3	5	*	3	4	1
DARK STREAKS	2	3	2	1	1	3	*	3	4	1
DARK SPECKS DEBRIS	3	3	3	1	1	2	*	5	2	2
WELD LINE INTENSITY; DEPTH	1	1	1	1	1	1	*		1	1
BEST COLOR	LA	LA	LA	LA	LA	LA	*	A	A	A
WELD LINE JUNCTURE TO EDGE (inches)	OFF PART	OFF PART	OFF PART	OFF PART	OFF PART	OFF PART	*	N/A	1.125	1.125
WELD LINE JUNCT OFF CL (inches)	N/A	N/A	N/A	N/A	N/A	N/A	*	N/A	5/16 S	5/16 S
WELD LINE JUNCT DEPTH (inches)	N/A	N/A	N/A	N/A	N/A	N/A	*	N/A	SURFACE	SURFACE
Oil Craze 1-10 (edges)							*			
Oil Craze arch							*			
Oil Craze Const. Thickness Area							*			
Oil Craze sills							*			
DART TEST COUPONS (abc;d)	A;B;C;D					A;B;C;D	*	N/A		A;B;C;D
							*			
EVALUATION COMMENTS:							*	SHORT SHOT	OP IN OPTICAL AREA	
date code ==> yymmdd-panel number							*			
no inserts							*			
mold core - concve side of panels							*			
port side ==> left side when facing gate end fro							*			
short shot ==> intentional injection of less mat							*			
units:							*			
temperatures - deg F							*			
length or distance - inches							*			
time - seconds (unless minutes indicated)							*			
pressure - psi							*			

Table 2. Molding Process and Panel Evaluation Summary (continued)

S-92 Molding; Envirotech,									
Salt Lake; UT April 1992	ANELS	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	FIVR 1/2 in FLAT PANELS	
see note for cell A3									
RESIN TYPE	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	DOW 300-4	DOW 300-4	DOW 300-4	DOW 300-4
RESIN TYPE & PANEL TYPE	DOW XU73093.00L F	DOW XU73093.00L F	DOW XU73093.00L F	DOW XU73093.00L F	DOW XU73093.00L F	DOW 300-4 Flat -	DOW 300-4 Flat -	DOW 300-4 Flat -	DOW 300-4 Flat -
PROCESS NUMBER	MX2054	MX2054	MX2054	MX2054	MX2054	MX2051	MX2051	MX2051	MX2051
PANEL I.D. (YYMMDD-##)	920415-04	920415-05	920415-06	920415-07	920415-08	920415-01	920415-02	920415-03	920415-04
PANEL TYPE	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in
******************************	****************	****************	****************	****************	****************	****************	****************	****************	****************
MOLDING PARAMETERS:									
RESIN DRY TIME (HRS)									
ACCUMULATE TIME (min)									
ACCUMULATE QUANTITY (piston pos inches)									
ACCUMULATOR PURGE (before/after fill)									
TOD - NOZZLE IN; VALVE ROTATION	20:00	20:45	21:25	22:10	[illegible]:50	0:30	1:20	2:00	2:45
FILLING TIME (seconds)	14.3	14.42	14.64	14.38	11.64	9.12	16.14	15.21	16.35
INJECT PRESSURE MAX (psi)	750	750	750	750	750				
PACKING PRESSURE (psi)	750	750	750	750	750				
TOD - MOLD OPEN	20:30	21:15	21:55	22:40	23:20	01:00	01:50	02:30	03:15
MOLD TEMP DATA FILE (Y/N)									
MOLD CAV TEMP; FILL (deg F)	211	210	213	215	214	204	212	214	213
MOLD CORE TEMP; FILL (deg F)	216	214	220	219	219	207	211	217	219
MELT TEMP; NOZZLE TIP; FILL (deg F)	560	561	560	560	560	568	560	560	561
SCREW RPM	30	30	320	30	30	30	30	30	30
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.									
******************************	*************	*************	*************	*************	*************	*************	*************	*************	*************
MOLDED PANEL CHARACTERISTICS:	1/2; 5.5 MFI	1/2; 5.5 MFI	1/2; 5.5 MFI	1/2; 5.5 MFI	1/2; 5.5 MFI	1/2; 4 MFI	1/2; 4 MFI	1/2; 4 MFI	1/2; 4 MFI
(eval code 1 good; 10 bad)									
WEIGHT (pounds)	22.66	22.656	22.625	22.63	22.69	11.13	22.63	22.66	22.69
OVERALL QUALITY	2	2	2	3	2	10	2	4	3
SURFACE SPLAY; STREAKING	1	1	1	1	1	1	1	1	1
THICKENED EDGE SINK	5	6	6	7	5		6	6	6
BUBBLES	2	2	2	1	1	1	1	6	2
VOIDS	1	1	1	1	1		1	1	1
ORANGE PEEL	1	1	1	1	1		1	1	1
DARK STREAKS	1	1	1	2	2	3	3	1	2
DARK SPECKS DEBRIS	1	1	1	1	2	2	7	1	3
WELD LINE INTENSITY; DEPTH	1	1	1	1	1		1	1	1
BEST COLOR	A	A	A	A	A	BT	BT	BT	BT
WELD LINE JUNCTURE TO EDGE (inches)	1.0625	1.0625	1.0625	1.0625	1.0625	N/A	1.13	1.13	1.13
WELD LINE JUNCT OFF CL (inches)	5/16 S	7/16 S	7/16 S	7/16 S	7/16 S	N/A	3/8 S	3/8 S	3/8 S
WELD LINE JUNCT DEPTH (inches)	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE	N/A	SURFACE	SURFACE	SURFACE
Oil Craze 1-10 (edges)									
Oil Craze arch									
Oil Craze Const. Thickness Area									
Oil Craze sills									
DART TEST COUPONS (abc;d)									
EVALUATION COMMENTS:						NO bubbles; Short shot	Good panel; Left at Envirotech	Bubbles all in sill edges	only one bubble
date code ==> yymmdd-panel number									
no inserts									
mold core - concve side of panels									
port side ==> left side when facing gate end fro									
short shot ==> intentional injection of less mat									
units:									
temperatures - deg F									
length or distance - inches									
time - seconds (unless minutes indicated)									
pressure - psi									

Table 2. Molding Process and Panel Evaluation Summary (continued)

S-92 Molding, Envirotech,										
Salt Lake, UT April 1992	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	*	~~~~~~~~~~~~	~~~~~~~~~~~~	FIVR 3/4 in FLAT PANELS		~~~~~~~~~~~~
see note for cell A3					*					
RESIN TYPE	DOW 300-4	DOW 300-4	DOW 300-4	DOW 300-4	*	DOW 300-4	DOW 300-4	DOW 300-4	DOW 300-4	DOW 300-4
RESIN TYPE & PANEL TYPE	DOW 300-4 Flat -	DOW 300-4 Flat -	DOW 300-4 Flat	DOW 300-4 Flat -	*	DOW 300-4 Flat -	DOW 300-4 Flat -	DOW 300-4 Flat -	DOW 300-4 Flat -	DOW 300-4 Flat -
PROCESS NUMBER	MX2051	MX2051	MX2051	MX2051	*	MX2047	MX2047	MX2047	MX2047	MX2047
PANEL I.D. (YYMMDD-##)	920415-05	920415-06	920415-07	920415-08	*	920416-01	920416-02	920416-03	920416-04	920416-05
PANEL TYPE	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	*	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in
**	****************	****************	****************	****************	*	****************	****************	****************	****************	****************
MOLDING PARAMETERS:										
RESIN DRY TIME (HRS)					*					
ACCUMULATE TIME (min)					*					
ACCUMULATE QUANTITY (piston pos inches)					*	13.00	13.00	13.00	13.00	13.00
ACCUMULATOR PURGE (before/after fill)					*					
TOD - NOZZLE IN; VALVE ROTATION	3:30	4:30	5:15	5:55	*	7:55	8:50	9:45	11:15	12:15
FILLING TIME (seconds)	15.96	16.18	16.17	16.28	*	4.8	16.1	16.1	15.2	14.1
INJECT PRESSURE MAX (psi)					*	750	750	750	750	750
PACKING PRESSURE (psi)					*	750	750	750	750	750
TOD - MOLD OPEN	04:00	05:00	05:45	06:25	*	08:40	09:35	10:30	12:00	13:00
MOLD TEMP DATA FILE (Y/N)					*	N	N	N	N	N
MOLD CAV TEMP; FILL (deg F)	214	212	213	213	*	183	201	205	208	209
MOLD CORE TEMP; FILL (deg F)	219	217	218	218	*	185	206	209	213	213
MELT TEMP; NOZZLE TIP; FILL (deg F)	561	561	560	560	*	560	561	560	562	561
SCREW RPM	30	30	30	30	*					
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.					*					
**	*************	*************	*************	*************	*	*************	*************	*************	*************	*************
MOLDED PANEL CHARACTERISTICS:	1/2; 4 MPI	1/2; 4 MPI	1/2; 4 MPI	1/2; 4 MPI	*	3/4; 4 MPI	3/4; 4 MPI	3/4; 4 MPI	3/4; 4 MPI	3/4; 4 MPI
(eval code 1 good; 10 bad)					*					
WEIGHT (pounds)	22.69	22.66	22.66	22.69	*	8.56	29.69	29.56	29.56	29.56
OVERALL QUALITY	5	5	4	6	*	10	9	6	4	6
SURFACE SPLAY; STREAKING	3	4	1	2	*		2	8	1	6
THICKENED EDGE SINK	6	6	6	6	*		2	4	3	3
BUBBLES	4	2	4	6	*	8	3	2	9	3
VOIDS	1	1	1	1	*		1	1	1	1
ORANGE PEEL	3	3	1	1	*		1	4	1	1
DARK STREAKS	3	1	2	5	*	5	9	5	4	4
DARK SPECKS DEBRIS	5	3	3	2	*	7	1	1	5	2
WELD LINE INTENSITY; DEPTH	1	1	1	1	*		1	3	1	1
BEST COLOR	BT	BT	BT	BT	*	WW	BT	BT	BT	BT
WELD LINE JUNCTURE TO EDGE (inches)	1.13	1.13	1.13	1.13	*	N/A	OFF PANEL	OFF PANEL	OFF PANEL	OFF PANEL
WELD LINE JUNCT OFF CL (inches)	7/16 S	1/2 S	9/16 S	1/2 S	*	N/A	N/A	N/A	N/A	N/A
WELD LINE JUNCT DEPTH (inches)	SURFACE	SURFACE	SURFACE	SURFACE	*	N/A	N/A	N/A	N/A	N/A
Oil Craze 1-10 (edges)					*					
Oil Craze arch					*					
Oil Craze Const. Thickness Area					*					
Oil Craze sills					*					
DART TEST COUPONS (abc;d)					*		A;B;C;D			
					*					
EVALUATION COMMENTS:	Defects mostly in sill edges				*	Short shot (Very!)	Huge dark streak in center part of cushion	Surface streak on entire length		
date code ==> yymmdd-panel number					*					
no inserts					*					
mold core - concve side of panels					*					
port side ==> left side when facing gate end fro					*					
short shot ==> intentional injection of less mat					*					
units:					*					
temperatures - deg F					*					
length or distance - inches					*					
time - seconds (unless minutes indicated)					*					
pressure - psi					*					

Table 2. Molding Process and Panel Evaluation Summary (continued)

8-92 Molding; Envirotech;										
Salt Lake; UT April 1992	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	FIVR 1/2 Cone		~~~~~~~~~~~~
see note for cell A3									
RESIN TYPE	DOW 300-4	DOW 300-4	DOW 300-4	DOW 300-4	DOW 300-15	DOW 300-15	DOW 300-15	DOW 300-15	DOW 300-15
RESIN TYPE & PANEL TYPE	DOW 300-4 Flat -	DOW 300-4 Flat -	DOW 300-4 Flat -	DOW 300-4 Flat -	DOW 300-15 Cone -	DOW 300-15 Cone -	DOW 300-15 Cone -	DOW 300-15 Cone -	DOW 300-15 Cone -
PROCESS NUMBER	MX2047	MX2047	MX2047	MX2047	MX2057	MX2057	MX2057	MX2057	MX2057
PANEL I.D. (YYMMDD-##)	920416-06	920416-07	920416-08	920416-09	920421-01	920421-02	920421-03	920421-04	920421-05
PANEL TYPE	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Cone - 1/2 in	Cone - 1/2 in	Cone - 1/2 in	Cone - 1/2 in	Cone - 1/2 in
**	**************	**************	**************	**************	**************	**************	**************	**************	**************
MOLDING PARAMETERS:									
RESIN DRY TIME (HRS)									
ACCUMULATE TIME (min)									
ACCUMULATE QUANTITY (piston pos inches)	13.00	13.00	13.00	13.00	10.5	10.5	10.5	10.5	10.5
ACCUMULATOR PURGE (before/after fill)									
TOD - NOZZLE IN; VALVE ROTATION	13:20	14:15	15:20	15:40	12:20	13:15	14:05	14:50	15:35
FILLING TIME (seconds)	14.5	14.6	14.1	16.2	5.8	5.8	5	5.3	5.5
INJECT PRESSURE MAX (psi)	750	750	750	750	750	750	750	750	750
PACKING PRESSURE (psi)	750	750	750	750	750	750	750	750	750
TOD - MOLD OPEN	14:05	15:00	16:05	17:05	12:50	13:45	14:35	15:20	16:05
MOLD TEMP DATA FILE (Y/N)	N	N	N	N					
MOLD CAV TEMP; FILL (deg F)	209	211	209	213	155	160	167	170	174
MOLD CORE TEMP; FILL (deg F)	215	216	2213	217	144	151	161	164	166
MELT TEMP; NOZZLE TIP; FILL (deg F)	560	561	561	522	567	569	572	572	573
SCREW RPM					40	40	40	40	40
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.									
**	**************	**************	**************	**************	**************	**************	**************	**************	**************
MOLDED PANEL CHARACTERISTICS:	3/4; 4 MPI	3/4; 4 MPI	3/4; 4 MPI	3/4; 4 MPI					
(eval code 1 good; 10 bad)									
WEIGHT (pounds)	29.56	29.63	29.69	29.69	14.25	12.1875	15.4375		
OVERALL QUALITY	7	6	5	5	10	7	5	4	3
SURFACE SPLAY; STREAKING	6	5	6	5	2	1	1	1	1
THICKENED EDGE SINK	3	3	4	3	10	1	1	1	1
BUBBLES	2	2	2	3	1	1	1	1	1
VOIDS	1	1	1	1	10	1	1	1	1
ORANGE PEEL	6	4	3	5	1	1	1	1	1
DARK STREAKS	5	4	4	3	1	2	1	1	1
DARK SPECKS DEBRIS	2	2	2	2	1	1	3	1	3
WELD LINE INTENSITY; DEPTH	1	1	1	1					
BEST COLOR	BT	BT	BT	BT	ww	ww	ww	ww	ww
WELD LINE JUNCTURE TO EDGE (inches)	OFF PANEL	OFF PANEL	OFF PANEL	OFF PANEL					
WELD LINE JUNCT OFF CL (inches)	N/A	N/A	N/A	N/A					
WELD LINE JUNCT DEPTH (inches)	N/A	N/A	N/A	N/A					
Oil Craze 1-10 (edges)									
Oil Craze arch					9	5	5	3	1
Oil Craze Const. Thickness Area						8	5	4	4
Oil Craze sills						7	5	3	3
DART TEST COUPONS (abc;d)				A;B;C;D					
EVALUATION COMMENTS:									Machine gate
date code ==> yymmdd-panel number									
no inserts									
mold core - concve side of panels									
port side ==> left side when facing gate end fro									
short shot ==> intentional injection of less mat									
units:									
temperatures - deg F									
length or distance - inches									
time - seconds (unless minutes indicated)									
pressure - psi									

Table 2. Molding Process and Panel Evaluation Summary (continued)

S-92 Molding, Envirotech,			*								*
Salt Lake, UT April 1992	~~~~~~~~~~~~	~~~~~~~~~~~~	*	~~~~~~~~~~~~	~~~~~~~~~~~~	FIVR Cone		~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	*
see note for cell A3			*								*
RESIN TYPE	DOW 300-15	DOW 300-15	*	DOW 300-6	DOW 300-6	DOW 300-6	DOW 300-6	DOW 300-6	DOW 300-6	DOW 300-6	*
RESIN TYPE & PANEL TYPE	DOW 300-15 Cone -	DOW 300-15 Cone -	*	DOW 300-6 Cone -1	DOW 300-6 Cone -1	DOW 300-6 Cone -1	DOW 300-6 Cone -1	DOW 300-6 Cone -1	DOW 300-6 Cone -1	DOW 300-6 Cone -1	*
PROCESS NUMBER	MX2057	MX2057	*	MX2056	MX2056	MX2056	MX2056	MX2056	MX2056	MX2056	*
PANEL I.D. (YYMMDD-##)	920421-06	920421-07	*	920421-01	920421-02	920421-03	920421-04	920421-05	920421-06	920421-07	*
PANEL TYPE	Cone - 1/2 in	Cone - 1/2 in	*	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	*
**	**************	**************	*	**************	**************	**************	**************	**************	**************	**************	*
MOLDING PARAMETERS:											
RESIN DRY TIME (HRS)			*								*
ACCUMULATE TIME (min)			*								*
ACCUMULATE QUANTITY (piston pos inches)	10.5	10.5	*	10.5	10.5	10.5					*
ACCUMULATOR PURGE (before/after fill)			*				before 1/2 in	before 1/2 in			*
TOD - NOZZLE IN; VALVE ROTATION	16:25	17:40	*	19:00	19:40	20:35	21:20	22:00	22:35	23:15	*
FILLING TIME (seconds)	4.9	6	*	6.9	8.52	9.76	9.19	9.56	9.26	9.75	*
INJECT PRESSURE MAX (psi)	750	750	*	750	750	750	750	750	750	750	*
PACKING PRESSURE (psi)	750	750	*	750	750	750	750	750	750	750	*
TOD - MOLD OPEN	16:55	17:40	*	19:30	20:10	21:05	21:50	22:30	23:05	23:45	*
MOLD TEMP DATA FILE (Y/N)			*								*
MOLD CAV TEMP; FILL (deg F)	176	180	*	176	178	181	184	183	185	186	*
MOLD CORE TEMP; FILL (deg F)	170	173	*	170	172	174	175	175	179	177	*
MELT TEMP; NOZZLE TIP; FILL (deg F)	573	573	*	574	576	573	573	573	573	573	*
SCREW RPM	40	40	*	37	37	37	37	37	37	37	*
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.			*								*
**	**************	**************	*	**************	**************	**************	**************	**************	**************	**************	*
MOLDED PANEL CHARACTERISTICS:			*								*
(eval code 1 good; 10 bad)			*								*
WEIGHT (pounds)			*	14.1875	15.5						*
OVERALL QUALITY	3	3	*	10	6	3	5	3	7	6	*
SURFACE SPLAY; STREAKING	1	1	*	3	4	1	3	2	4	1	*
THICKENED EDGE SINK	1	1	*	8	1	1	1	1	1		*
BUBBLES	1	1	*	5	1	1	1	1	1	1	*
VOIDS	1	1	*		1	1	1	1	1	1	*
ORANGE PEEL	1	1	*	1	1	1	1	1	3	3	*
DARK STREAKS	1	3	*	3	2	1	2	1	3	4	*
DARK SPECKS DEBRIS	2	1	*	4	1	1	3	1	1	3	*
WELD LINE INTENSITY; DEPTH			*								*
BEST COLOR	ww	ww	*	ww	ww	ww	ww	ww	ww	ww	*
WELD LINE JUNCTURE TO EDGE (inches)			*								*
WELD LINE JUNCT OFF CL (inches)			*								*
WELD LINE JUNCT DEPTH (inches)			*								*
Oil Craze 1-10 (edges)			*								*
Oil Craze arch	1		*	1	1	3	4	1	3	1	*
Oil Craze Const. Thickness Area	4	4	*	1	3	4	4	3	3	3	*
Oil Craze sills	3	5	*		2	3	2	3	2	2	*
DART TEST COUPONS (abc;d)			*								*
			*								*
EVALUATION COMMENTS:	Machice gate		*	No pack		machine gate			small splay optical area		*
date code ==> yymmdd-panel number			*								*
no inserts			*								*
mold core - concve side of panels			*								*
port side ==> left side when facing gate end fro			*								*
short shot ==> intentional injection of less mat			*								*
units:			*								*
temperatures - deg F			*								*
length or distance - inches			*								*
time - seconds (unless minutes indicated)			*								*
pressure - psi			*								*

Table 2. Molding Process and Panel Evaluation Summary (continued)

8-92 Molding; Envirotech;										
Salt Lake, UT April 1992	~~~~~~~~~~~~	~~~~~~~~~~~~	FIVR 1/2 Cone		~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	*	~~~~~~~~~~~~	FIVR 1/2 in Cone
see note for cell A3								*		
RESIN TYPE	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	*	DOW 300-4	DOW 300-4
RESIN TYPE & PANEL TYPE	DOW XU73093.00L C	DOW XU73093.00L C	DOW XU73093.00L C	DOW XU73093.00L C	DOW XU73093.00L C	DOW XU73093.00L C	DOW XU73093.00L C	*	DOW 300-4 Cone -1	DOW 300-4 Cone -1
PROCESS NUMBER	MX2058	MX2058	MX2058	MX2058	MX2058	MX2058	MX2058	*	MX2055	MX2055
PANEL I.D. (YYMMDD-##)	920421-01	920421-02	920421-03	920421-04	920421-05	920421-06	920421-07	*	920422-01	920422-02
PANEL TYPE	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	*	Cone -1/2 in	Cone -1/2 in
**	**************	**************	**************	**************	**************	**************	**************	*	**************	**************
MOLDING PARAMETERS:								*		
RESIN DRY TIME (HRS)										
ACCUMULATE TIME (min)								*		
ACCUMULATE QUANTITY (piston pos inches)	10.5	10.5	10.5	10.5	10.5	10.5	10.5	*	10.5	10.5
ACCUMULATOR PURGE (before/after fill)								*		
TOD - NOZZLE IN; VALVE ROTATION	0:30	1:05	1:50	2:30	3:30	4:20	6:25	*	8:20	9:05
FILLING TIME (seconds)	7.41	7.47	8.27	8.23	8.3	8.64	6.3	*	9.5	10.2
INJECT PRESSURE MAX (psi)	750	750	750	750	750	750	750	*	750	750
PACKING PRESSURE (psi)	750	750	750	750	750	750	750	*	750	750
TOD - MOLD OPEN	01:00	01:35	02:20	03:00	04:00	04:50	06:55	*	08:50	09:35
MOLD TEMP DATA FILE (Y/N)								*		
MOLD CAV TEMP; FILL (deg F)	176	180	181	180	181	181	169	*	164	168
MOLD CORE TEMP; FILL (deg F)	170	172	176	174	175	174	163	*	157	160
MELT TEMP; NOZZLE TIP; FILL (deg F)	574	574	574	573	573	571	576	*	574	572
SCREW RPM	35	35	35	35	35	35	35	*	30	30
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.								*		
**	**************	**************	**************	**************	**************	**************	**************	*	**************	**************
MOLDED PANEL CHARACTERISTICS:								*		
(eval code 1 good; 10 bad)								*		
WEIGHT (pounds)	14.375	15.5						*	14.4375	
OVERALL QUALITY	10	6	8	8	7	8	8	*	10	4
SURFACE SPLAY; STREAKING	2	5	7	7	6	8	3	*	4	2
THICKENED EDGE SINK		1	1	1	1	1	1	*		1
BUBBLES	2	1	1	1	2	1	1	*	1	1
VOIDS		1	1	1	1	1	1	*	1	1
ORANGE PEEL	1	1	1	3	3	4	1	*	1	1
DARK STREAKS	3	2	4	1	2	2	6	*	3	1
DARK SPECKS DEBRIS	1	1	2	3	5	2	3	*	3	3
WELD LINE INTENSITY; DEPTH								*		
BEST COLOR	Amber	Amber	Amber	Amber	Amber	Amber	Amber	*	BT	BT/Amber
WELD LINE JUNCTURE TO EDGE (inches)								*		
WELD LINE JUNCT OFF CL (inches)								*		
WELD LINE JUNCT DEPTH (inches)								*		
Oil Craze 1-10 (edges)								*		
Oil Craze arch	1	1	2	2	2	2	2	*	1	1
Oil Craze Const. Thickness Area	2	4	2	2	2	2	3	*	1	2
Oil Craze sills	1	3	2	1	2	3	2	*	1	1
DART TEST COUPONS (abc;d)								*		
EVALUATION COMMENTS:			Splay/streak of optical area					*	No Pack	material slightly overprocessed color going from BT to amber
date code ==> yymmdd-panel number										
no inserts								*		
mold core - concve side of panels								*		
port side ==> left side when facing gate end fro								*		
short shot ==> intentional injection of less mat								*		
units:								*		
temperatures - deg F								*		
length or distance - inches								*		
time - seconds (unless minutes indicated)								*		
pressure - psi								*		

Table 2. Molding Process and Panel Evaluation Summary (concluded)

8-92 Molding; Envirotech;					*
Salt Lake; UT April 1992		~~~~~~~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~	*
see note for cell A3					*
RESIN TYPE	DOW 300 4	DOW 300-4	DOW 300-4	DOW 300-4	*
RESIN TYPE & PANEL TYPE	DOW 300 4 Cone -1/	DOW 300-4 Cone -1/	DOW 300-4 Cone -1/	DOW 300-4 Cone -1/	*
PROCESS NUMBER	MX2055	MX2055	MX2055	MX2055	*
PANEL I.D. (YYMMDD-##)	920422-03	920422-04	920422-05	920422-06	*
PANEL TYPE	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	*
**	****************	****************	****************	****************	*
MOLDING PARAMETERS:					
RESIN DRY TIME (HRS)					*
ACCUMULATE TIME (min)					*
ACCUMULATE QUANTITY (piston pos inches)	10.5	10.5	10.5	10.5	*
ACCUMULATOR PURGE (before/after fill)					*
TOD - NOZZLE IN; VALVE ROTATION	9:50	10:35	12:05	12:50	*
FILLING TIME (seconds)	10.5	9.8	9.1	9	*
INJECT PRESSURE MAX (psi)	750	750	750	750	*
PACKING PRESSURE (psi)	750	750	750	750	*
TOD - MOLD OPEN	10:20	11:05	12:35	13:20	*
MOLD TEMP DATA FILE (Y/N)					*
MOLD CAV TEMP; FILL (deg F)	172	174	172	174	*
MOLD CORE TEMP; FILL (deg F)	166	167	166	168	*
MELT TEMP; NOZZLE TIP; FILL (deg F)	572	572	573	522	*
SCREW RPM	30	30	30	30	*
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.					*
					*
**	*************	*************	*************	*************	*
MOLDED PANEL CHARACTERISTICS:					*
(eval code 1 good; 10 bad)					*
WEIGHT (pounds)	16	14.4375			*
OVERALL QUALITY	5	5	3	7	*
SURFACE SPLAY; STREAKING	2	1	1	5	*
THICKENED EDGE SINK	1	1	1	1	*
BUBBLES	1	1	1	1	*
VOIDS	1	1	1	1	*
ORANGE PEEL	1	1	1	5	*
DARK STREAKS	1	1	1	3	*
DARK SPECKS DEBRIS	2	3	4	2	*
WELD LINE INTENSITY; DEPTH					*
BEST COLOR	Amber	Amber	BT	Amber	*
WELD LINE JUNCTURE TO EDGE (inches)					*
WELD LINE JUNCT OFF CL (inches)					*
WELD LINE JUNCT DEPTH (inches)					*
Oil Craze 1-10 (edges)					*
Oil Craze arch	1	1	4	2	*
Oil Craze Const. Thickness Area	2	2	2	2	*
Oil Craze sills	1	1	1	1	*
DART TEST COUPONS (abc;d)					*
					*
EVALUATION COMMENTS:	Send to GD; overprocessed material	overprocessed material		overprocessed again	*
date code ==> yymmdd-panel number					*
no inserts					*
mold core - concve side of panels					*
port side ==> left side when facing gate end fro					*
short shot ==> intentional injection of less mat					*
units:					*
temperatures - deg F					*
length or distance - inches					*
time - seconds (unless minutes indicated)					*
pressure - psi					*

Schedules were in three day increments with 3 consecutive days of work and 3 consecutive days off from work. Shifts A & C worked 6AM to 6PM, and shifts B & D worked 6PM to 6AM. The table below shows the shift schedule while WL/FIVR was at Envirotech in April, 1992.

```
                 <-A-><-D-><-C-><-D-><-C-><-D-><-C-><-B-><-A-><-B-><-A-><-B-
6A   6P   6A   6P   6A   6P   6A   6P   6A   6P   6A   6P   6A   6P
--12th--|---13th--|---14th--|---15th--|---16th--|---17th--|---18th--|
 SUNDAY    MONDAY    TUESDAY  WEDNESDAY  THURSDAY   FRIDAY   SATURDAY

><-A-><-D-><-C-><-D-><-C-><-D-><-C-><-B-><-A-><-B-><-A->
6A   6P   6A   6P   6A   6P   6A   6P   6A   6P   6A   6P   6A   6P
--19th--|---20th--|---21st--|---22nd--|---23rd--|---24th--|---25th--|
 SUNDAY    MONDAY    TUESDAY  WEDNESDAY  THURSDAY   FRIDAY   SATURDAY
```

An important point to note is that the date changed at shift turnover at 6AM, *not at midnight.* The date code on the process sheets can indicate a part was molded at 0215 on the 14th when the actual date is 0215 on the 15th. This is because the date did not change until 6AM when the day shift starts.

MACH NO. - Envirotech has designated their machines as P-1 through P-x The machine used for molding is entered here. The WL/FIVR molding was done on P-2.

DATE CODE - This number, along with the "MX" number, uniquely identifies a part for the molding in April, 1992. The date code is entered in the following format; YYMMDD-shot number. A typical entry is "920413-03," which indicates 13 APR 92, shot number 3.

SHOT TIME - The time of day the molten resin was injected into the mold is entered here. On some sheets this may be labeled as LOAD START TIME or START TIME.

REMOVE TIME - The time of day the part is removed from the mold is entered here. On some sheets this may be labeled as LOAD END TIME or END TIME.

MOLD TEMP. - The operator reads temperatures from a pyrometer held against the mold surfaces just prior to closing the mold and before shooting the part. The temperatures of the top half (cavity) and bottom half (core) are recorded here.

MELT TEMP. - The P-2 machine has a thermocouple in the melt path between the screw and the accumulator. This thermocouple registers the temperature of the melt and sends it to the digital readout labeled "Melt Temperature" on the molding machine instrument panel. This temperature reading is recorded in this space. It is important to note that this melt temperature may not be the temperature of the resin at the nozzle.

INJECTION PRESSURE - The mold operator reads a gauge that indicates the pressure of the hydraulic fluid that drives the accumulator piston. Next to the gauge is a conversion plaque that lists hydraulic fluid pressures and "injection pressures." The operator looks at the gauge and then finds the appropriate "injection pressure" that corresponds to the gauge reading. The operator then records the "injection pressure" on the process sheet. The true injection pressure is 10 times the number recorded by the operator. This 10:1 factor is a carryover from the days of using pneumatics instead of hydraulics. A typical entry on the INJECTION PRESSURE line is "75." This correlates to a true injection pressure of 750 psi (75 x 10 psi).

INJECTION SPEED SETTING - The accumulator's maximum injection rate (speed) is governed by the accumulator components, associated hydraulics, and the resin used. The injection speed setting can be set at a percentage of the maximum (i.e., 80% of maximum). For the molding in April, 1992, this setting was always at 100%.

FILL TIME - The time, in seconds, required to fill the mold with resin is entered here. A time count was initiated when the nozzle contacted the mold and the mold began to fill. The time count was stopped when the accumulator piston stopped moving.

PACK PRESSURE - After the mold was filled, a constant pressure was kept on the accumulator piston, forcing additional molten resin into the mold as the part cooled and shrank. This packing pressure, which is entered here, typically forced an additional pound of resin into the mold as the part cooled. Pack pressure was typically set at 750 psi.

PACK TIME - ACTUAL - The length of time the pack pressure was applied is entered here. Typically, this was 30 minutes.

DRYER CONDITIONS: TEMPERATURE, TIME - The dryer was used to remove moisture from the resin before the resin was melted in the extruder by the screw. For all of the resins used, Dow recommends at least three hours at 250°F for drying Dow Calibre 300-6 resin. The temperature and amount of time used for drying the resin are entered here.

MACHINE CONDITIONS - The 2 columns in this section have lines for recording the set and actual temperatures in 11 different zones of the molding machine. Zone temperatures were independently controlled through separate electric heater bands. A set point temperature was entered for each heater band, and a thermocouple at each zone gave the actual temperature. It should be noted that the "DIE ZONE" was the only zone that has a thermocouple directly in the molten resin path. All other thermocouples were external to the resin path.

The 11 zones listed in this section were approximately in the same order as the flow of resin through the machine. Zone 1 received resin first, then zones 2, 3, and 4. The die zone was directly after the extruder. The head zone was at the top of the accumulator, and the valve zone was located at the valve on the bottom of the accumulator. The gun top and gun bottom zones were located on the nozzle barrel close to the accumulator, while the nozzle tube was located closer to the end of the nozzle. The nozzle tip was the last zone the resin flowed through before injection.

SCREW SPEED - The rotational speed of the extruder screw is entered here.

2.2.2.3 Data Acquisition - LabVIEW System

LabVIEW had been selected as the data acquisition system for future CFT molding. The CFT molding would be different from panel molding because the CFT mold would be instrumented with thermocouples and pressure sensors for monitoring and controlling the heating and cooling of the mold.

The LabVIEW system was installed at the Envirotech molding machine during this effort in order to gain initial experience with the system and to reveal potential

problems in acquiring data. The LabVIEW subeffort was separate from the original scope of the subject effort and was funded separately. However, the LabVIEW subeffort is noted here because it took place during this subject effort and has not been documented elsewhere.

The LabVIEW system is a software package marketed by National Instruments, Inc. of Austin, TX. LabVIEW runs on a high end MacIntosh personal computer and requires several other specialized components (i.e., data acquisition boards, instrument drivers, data bus interface, etc.). LabVIEW provides for data acquisition through a user interface of Virtual Instruments (VIs), which are icon-like figures on the computer screen. The VIs are programmed in a graphical programming environment to acquire data from sensors, such as temperature from a thermocouple, at user specified intervals.

A thermocouple was attached to each mold half and data lines were run to the LabVIEW system. VIs and sensors were calibrated, and mold temperature readings were acquired. Important lessons learned during the LabVIEW subeffort during these molding trials were:

1) Electronic noise from the molding machinery corrupted the acquired data. Special data line shielding requirements were identified.
2) Inconsistencies in hardware recommendations were identified. For example, boards preconfigured for this subeffort had to be rejumpered.
3) When all components were configured correctly and the noise problem was solved, accurate temperature readings were acquired at satisfactory intervals.

2.3 On-Site Evaluation

Some testing and evaluation were performed during molding sessions. Molding of each group of panels required 10-12 hours. This time included mold setup, molding machine setup, initial accumulation and purges of material, and molding of the 6-8 panels. An effort was made to drop dart test the first or second panel of each group after it cooled to room temperature (2-3 hours after molding). The results of on-site testing and evaluation were considered as

confirmation that the molding process was producing adequate panel ductility and quality. These results were used to make process adjustments as necessary.

There was neither time nor resources to evaluate and test each panel after it cooled. The nature of the molding trials necessitated frequent changes of mold, molding machine, and resin. Therefore, time was available between groups of panels to test and evaluate panels.

2.3.1 Qualitative Panel Evaluation

The panels were evaluated by the two USAF engineers. The evaluators performed independent evaluations on representative panels several times to demonstrate compatibility in evaluation results. Panel evaluation results are shown in the lower rows of Table 2, identified as "Molded Panel Characteristics."

Panels were evaluated in up to 16 detailed categories with an overall score given which represented the panel overall quality. The subjective scores ranged from 1-10, with 1 representing "Good" quality and 10 representing "Bad" quality. Table 2 shows every score for each panel, while Table 3 summarizes the evaluation results.

Table 3. Average Overall Quality Scores.

Flat Panels				Conical Panels			
1)	1/2"	XU7-5.5	SCORE=3.6	1)	1/2"	300-15	SCORE=5.0
2)	1/2"	300-15	SCORE=4.6	2)	1/2"	300-4	SCORE=5.7
3)	3/4"	XU7-5.5	SCORE=4.7	3)	1/2"	300-6	SCORE=5.7
4)	1/2"	300-4	SCORE=4.9	4)	1/2"	XU7-5.5	SCORE=7.9
5)	3/4"	300-6	SCORE=5.8				
6)	3/4"	300-4	SCORE=6.4				
7)	1/2"	300-6	SCORE=6.6				
8)	3/4"	300-15	SCORE=6.8				

Some key results of the evaluation were:

- The group of flat panels with the best overall quality (average of 8 panels = 3.6) were 1/2-inch panels molded from the Dow experimental resin, XU7-5.5.

- The group of 3/4-inch flat panels with the best overall quality (average of 8 panels = 4.7) were also molded from Dow XU7-5.5.

- The group of cones with the best overall quality (average of 7 cones = 5.0) were molded from Dow 300-15, while the experimental resin, Dow XU7-5.5, resulted in the worst overall rating for the cones.

- Thickened edge sink in the flat panels was less pronounced in the 3/4-inch panels than in the 1/2-inch panels. Also, sink was more pronounced as the MFI decreased.

- The 1/2-inch panels generally scored better in overall quality because of less surface splay, bubbles/voids, and orange peel. An exception was the Dow 300-6 resin, in which 3/4-inch panels scored better than the 1/2-inch panels.

- For all panels the weights recorded indicate that packing added approximately 1.2 pounds of material to the panels.

2.3.2 Drop Dart Testing

The apparatus used for drop dart testing is shown in Figure 11 (photo dated January, 1990). The dart apparatus shown was modified for the subject effort with the addition of improved clamps for the sample holder, adjustable weights on the dart, and a sliding "catching" mechanism to prevent a second strike by a rebounding dart. The spherical nose of the dart could be configured with different weights resulting in dart weights between 20 and 67 pounds. The dart could be dropped from a maximum height of 21.5 feet.

Drop dart testing was accomplished on flat panel coupons only. The panels were marked with a template on the concave (core) side with the arch of the panel toward the engineer and the gate away from the engineer. With the panel in this orientation, the left thickened edge was the port side, and the right edge was the starboard side. (Note: the use of the terms "port"

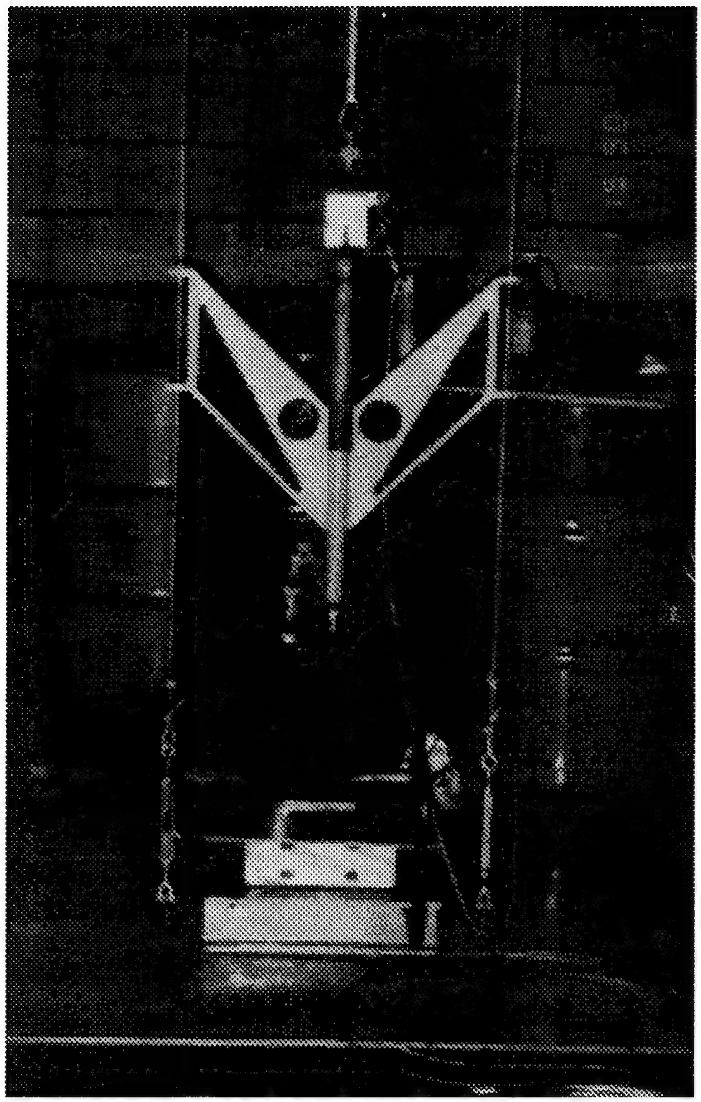


Figure 11. Drop Dart Apparatus.

and "starboard" evolved as an attempt to reduce confusion involved in using "left" and "right." "Left" and "right" always needed an additional qualifier of panel orientation.) Since a template was used to mark the panels, the coupons were cut from approximately the same locations in the constant thickness (optical) section of each panel. Coupon A was located on the starboard side, arch end; coupon B on the port side, arch end; coupon C on the port side, gate end; and coupon D on the starboard side, gate end. The coupon locations are shown schematically in Figure 12.

A total of 17 panels were cut for dart tests yielding 68 coupons. Sixty-seven of these were tested on-site. All but 1 of the 67 were impacted from the maximum height (21.5 feet) with the heaviest dart configuration (67 lb). Thirty-six coupons were impacted on the core side, and 31 coupons were impacted on the cavity side. Only 6 of the 67 coupons failed the impact test. Additionally, one coupon almost failed; the impact resulted in a 3/4-inch crack on the underside of the impact bulge. Five of the failed coupons were impacted from the cavity side, and one failed coupon was impacted from the core side. Only one of the failed coupons showed signs of brittle behavior. The drop dart test results are shown in Table 4, and the failed coupon information is summarized below:

- 1 failed 3/4-inch Dow 300-15 impacted from cavity side
- 2 failed 1/2-inch Dow 300-15 impacted from cavity side
- 1 failed 1/2-inch Dow 300-6 impacted from cavity side
- 1 failed 3/4-inch Dow 300-4 impacted from cavity side
- 1 failed 3/4-inch Dow 300-4 impacted from core side
- 1 cracked 1/2-inch Dow XU7-5.5 impacted from cavity side

The 3/4-inch coupons that failed all came from panels with some flaws. The 3/4-inch Dow 300-15 failed coupon came from a panel with severe surface splay. This panel had a longer filling time (up to 3+ seconds) than other panels in the group, indicating a probable lower melt temperature. (Note: the melt temperature reported at the molding machine is NOT the temperature of the resin at the nozzle, it is the temperature of the resin between the extruder and the accumulator.) This lower melt temperature may have caused brittleness at the surfaces of the panel. The 3/4-inch Dow 300-4 failed coupons came from a panel with a large brown

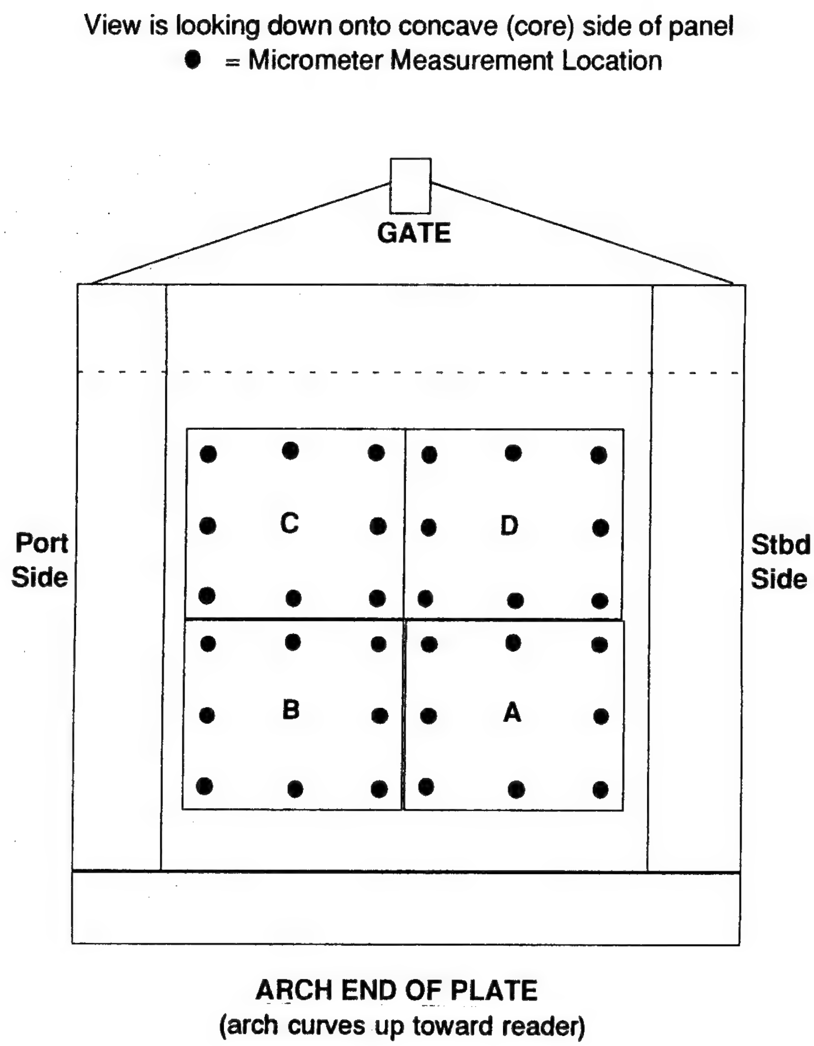


Figure 12. Coupon and Micrometer Measurement Locations.

Table 4. Drop Dart Test Results

S-92 Molding; Envirotech;							
Salt Lake; UT April 1992	FIVR 3/4 in FLAT PANELS		------------	FIVR 1/2 in FLAT P ------------		------------	------------
see note for cell A3							
RESIN TYPE	Dow 300 15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-6	Dow 300-6
PROCESS NUMBER	MX2049	MX2049	MX2049	MX2053	MX2053	MX2052	MX2052
PANEL I.D. (YYMMDD-##)	920413-03	920413-04	920413-06	920414-03	920414-07	920414-02	920414-08
PANEL TYPE	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in
DART TEST DATA:							
Dart coupon A table descriptor	DART SPEC A	DART SPEC A	DART SPEC A	DART SPEC A	DART SPEC A	DART SPEC A	DART SPEC A
TEST DATE (dd-mmm-yy)	15-Apr-92	15-Apr-92	17-Apr-92	16-Apr-92	16-Apr-92	16-Apr-92	17-Apr-92
Time of Day for Testing (hh:mm)		11:30		10:00	10:00	11:00 HRS	
Dart Test Specimen Type	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in
IMPACT SIDE	core	core	core	core	cavity	Core	Core
WEIGHT (lbs.)	47.00	67.00	67.00	67.00	67.00	67.00	67.00
HEIGHT (ft.)	20.00	21.50	21.50	21.50	21.50	21.50	21.50
ENERGY (ft-lbs)	940.00	1440.50	1440.50	1440.50	1440.50	1440.50	1440.50
RESULT	ductile	ductile	ductile	ductile	**FAILED**	ductile	ductile
COMMENTS	panel not packed	new nose	tested 15Apr				
Dart coupon B table descriptor	DART SPEC B	DART SPEC B	DART SPEC B	DART SPEC B	DART SPEC B	DART SPEC B	DART SPEC B
TEST DATE (dd-mmm-yy)	15-Apr-92	15-Apr-92	17-Apr-92	16-Apr-92	16-Apr-92	16-Apr-92	17-Apr-92
Time of Day for Testing (hh:mm)		11:30		10:00	10:00	11:00 HRS	
Dart Test Specimen Type	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in
IMPACT SIDE	core	core	cavity	core	core	Cavity	Cavity
WEIGHT (lbs.)	67.00	67.00	67.00	67.00	67.00	67	67
HEIGHT (ft.)	21.50	21.50	21.50	21.50	21.50	21.5	21.5
ENERGY (ft-lbs)	1440.50	1440.50	1440.50	1440.50	1440.50	1440.50	1440.50
RESULT	ductile	ductile	ductile	ductile	ductile	**FAILED**	ductile
COMMENTS	panel not packed			double hit			
Dart coupon C table descriptor	DART SPEC C	DART SPEC C	DART SPEC C	DART SPEC C	DART SPEC C	DART SPEC C	DART SPEC C
TEST DATE (dd-mmm-yy)	15-Apr-92	15-Apr-92	17-Apr-92	16-Apr-92	16-Apr-92	16-Apr-92	17-Apr-92
Time of Day for Testing (hh:mm)		11:30		10:00	10:00	11:00 HRS	
Dart Test Specimen Type	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in
IMPACT SIDE	core	cavity	cavity	core	cavity	Core	Cavity
WEIGHT (lbs.)	67.00	67.00	67.00	67.00	67.00	67	67
HEIGHT (ft.)	21.50	21.50	21.50	21.50	21.50	21.5	21.5
ENERGY (ft-lbs)	1440.50	1440.50	1440.50	1440.50	1440.50	1440.50	1440.50
RESULT	ductile	**FAILED**	ductile	ductile	ductile	ductile	ductile
COMMENTS	panel not packed	severe splay/o.p.;	little plastic def			New nose	
Dart coupon D table descriptor	DART SPEC D	DART SPEC D	DART SPEC D	DART SPEC D	DART SPEC D	DART SPEC D	DART SPEC D
TEST DATE (dd-mmm-yy)	15-Apr-92	15-Apr-92	17-Apr-92	16-Apr-92	16-Apr-92	16-Apr-92	17-Apr-92
Time of Day for Testing (hh:mm)		11:30		10:00	10:00	11:00 HRS	
Dart Test Specimen Type	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in	Square 6x6 in
IMPACT SIDE	core	core	cavity	core	cavity	Cavity	Cavity
WEIGHT (lbs.)	67.00	67.00	67.00	67.00	67.00	67	67
HEIGHT (ft.)	21.50	21.50	21.50	21.50	21.50	21.5	21.5
ENERGY (ft-lbs)	1440.50	1440.50	1440.50	1440.50	1440.50	1440.50	1440.50
RESULT	ductile	ductile	ductile	ductile	**FAILED**	ductile	ductile
COMMENTS	panel not packed	some splay; tested 17Apr; 0900hrs		double hit			
GENERAL DART TEST COMMENTS:	control (7/16 in extruded polycarbonate) sample ductile when impacted by 47 lb dart dropped from 15 feet (1445.5 ftlb = 67lbs*21.5ft)						

Table 4. Drop Dart Test Results (continued)

S-92 Molding; Envirotech;			*			*			*	
Salt Lake; UT April 1992	--------------	------------	*	FIVR 3/4 in FLAT F ------------		*	FIVR 1/2 in FLAT F ------------		*	FIVR 1/2 in FLAT F
see note for cell A3			*			*			*	
RESIN TYPE	Dow 300-6	Dow 300-6	*	DOW XU73093.00L	DOW XU73093.00L	*	DOW XU73093.00L	DOW XU73093.00L	*	DOW 300-4
PROCESS NUMBER	MX2048	MX2048	*	MX2050	MX2050	*	MX2054	MX2054	*	MX2051
PANEL I.D. (YYMMDD-##)	920414-2	920414-06	*	920415-03	920415-08	*	920415-03	920415-08	*	920415-03
PANEL TYPE	Flat - 3/4 in	Flat - 3/4 in	*	Flat - 3/4 in	Flat - 3/4 in	*	Flat - 1/2 in	Flat - 1/2 in	*	Flat - 1/2 in
**************************	**************	**************	*	**************	**************	*	**************	**************	*	**************
DART TEST DATA:			*			*			*	
			*			*			*	
Dart coupon A table descriptor	DART SPEC A	DART SPEC A	*	DART SPEC A	DART SPEC A	*	DART SPEC A	DART SPEC A	*	DART SPEC A
			*			*			*	
TEST DATE (dd-mmm-yy)	20-Apr-92	20-Apr-92	*	17-Apr-92	17-Apr-92	*	21-Apr-92	21-Apr-92	*	20-Apr-92
Time of Day for Testing (hh:mm)			*	15:00	15:00	*			*	
Dart Test Specimen Type	Square 6x6 in	Square 6x6 in	*	Square 6x6 in	Square 6x6 in	*	Square 6x6 in	Square 6x6 in	*	Square 6x6 in
IMPACT SIDE	Core	Cavity	*	Core	Core	*	Cavity	Core	*	Cavity
WEIGHT (lbs.)	67.00	67	*	67.00	67.00	*	67	67.00	*	67.00
HEIGHT (ft.)	21.50	21.5	*	21.50	1440.50	*	21.5	21.50	*	21.50
ENERGY (ft-lbs)	1440.50	1440.50	*	1440.5	1440.5	*	1440.5	1440.50	*	1440.5
RESULT	ductile	ductile	*	Ductile	Ductile	*	Ductile	Ductile	*	Ductile
COMMENTS			*			*			*	20-Apr-92
			*			*			*	
Dart coupon B table descriptor	DART SPEC B	DART SPEC B	*	DART SPEC B	DART SPEC B	*	DART SPEC B	DART SPEC B	*	DART SPEC B
			*			*			*	
TEST DATE (dd-mmm-yy)	20-Apr-92	20-Apr-92	*	17-Apr-92	17-Apr-92	*	21-Apr-92	21-Apr-92	*	20-Apr-92
Time of Day for Testing (hh:mm)			*	15:00	15:00	*			*	
Dart Test Specimen Type	Square 6x6 in	Square 6x6 in	*	Square 6x6 in	Square 6x6 in	*	Square 6x6 in	Square 6x6 in	*	Square 6x6 in
IMPACT SIDE	Cavity	Core	*	Cavity	Cavity	*	Core	Cavity	*	Core
WEIGHT (lbs.)	67	67.00	*	67	67	*	67	67.00	*	67.00
HEIGHT (ft.)	21.5	21.50	*	21.5	21.5	*	21.5	21.50	*	21.50
ENERGY (ft-lbs)	1440.50	1440.50	*	1440.5	1440.5	*	1440.5	1440.5	*	1440.5
RESULT	ductile	ductile	*	Ductile	Ductile	*	Ductile	Ductile	*	Ductile
COMMENTS			*			*		3/4" Tens. Crack	*	20-Apr-92
			*			*			*	
Dart coupon C table descriptor	DART SPEC C	DART SPEC C	*	DART SPEC C	DART SPEC C	*	DART SPEC C	DART SPEC C	*	DART SPEC C
			*			*			*	
TEST DATE (dd-mmm-yy)	20-Apr-92	20-Apr-92	*	17-Apr-92	17-Apr-92	*	21-Apr-92	21-Apr-92	*	20-Apr-92
Time of Day for Testing (hh:mm)			*	15:00	15:00	*			*	
Dart Test Specimen Type	Square 6x6 in	Square 6x6 in	*	Square 6x6 in	Square 6x6 in	*	Square 6x6 in	Square 6x6 in	*	Square 6x6 in
IMPACT SIDE	Core	Cavity	*	Core	Core	*	Cavity	Core	*	Cavity
WEIGHT (lbs.)	67.00	67	*	67	67	*	67	67.00	*	67.00
HEIGHT (ft.)	21.50	21.5	*	21.5	21.5	*	21.5	21.50	*	21.50
ENERGY (ft-lbs)	1440.50	1440.50	*	1440.5	1440.5	*	1440.5	1440.50	*	1440.5
RESULT	ductile	ductile	*	Ductile	Ductile	*	Ductile	Ductile	*	Ductile
COMMENTS			*			*			*	20-Apr-92
			*			*			*	
Dart coupon D table descriptor	DART SPEC D	DART SPEC D	*	DART SPEC D	DART SPEC D	*	DART SPEC D	DART SPEC D	*	DART SPEC D
			*			*			*	
TEST DATE (dd-mmm-yy)	20-Apr-92	20-Apr-92	*	17-Apr-92	17-Apr-92	*	21-Apr-92	21-Apr-92	*	20-Apr-92
Time of Day for Testing (hh:mm)			*	15:00	15:00	*			*	
Dart Test Specimen Type	Square 6x6 in	Square 6x6 in	*	Square 6x6 in	Square 6x6 in	*	Square 6x6 in	Square 6x6 in	*	Square 6x6 in
IMPACT SIDE	Cavity	Core	*	Cavity	Cavity	*	Core	Cavity	*	Core
WEIGHT (lbs.)	67	67.00	*	67	67	*	67	67.00	*	67.00
HEIGHT (ft.)	21.5	21.50	*	21.5	21.5	*	21.5	21.50	*	21.50
ENERGY (ft-lbs)	1440.50	1440.50	*	1440.5	1440.5	*	1440.5	1440.50	*	1440.5
RESULT	ductile	ductile	*	Ductile	Ductile	*	Ductile	Ductile	*	Ductile
COMMENTS			*			*			*	20 Apr-92
**************************	**************	**************	*	**************	**************	*	**************	**************	*	**************
GENERAL DART TEST COMMENTS: contr[illegible]l	(7/16 in ex									

Table 4. Drop Dart Test Results (concluded)

S-92 Molding; Envirotech;		*			*
Salt Lake; UT April 1992	~~~~~~~~~~~~	*	~~~~~~~~~~~~	~~~~~~~~~~~~	*
see note for cell A3		*			*
RESIN TYPE	DOW 300-4	*	DOW 300-4	DOW 300-4	*
PROCESS NUMBER	MX2051	*	MX2047	MX2047	*
PANEL I.D. (YYMMDD-##)	920415-08	*	920416-02	920416-09	*
PANEL TYPE	Flat - 1/2 in	*	Flat - 3/4 in	Flat - 3/4 in	*
**	*****************	*	*****************	*****************	*
DART TEST DATA:		*			*
		*			*
Dart coupon A table descriptor	DART SPEC A	*	DART SPEC A	DART SPEC A	*
		*			*
		*			*
TEST DATE (dd-mmm-yy)	20-Apr-92	*	20-Apr-92	20-Apr-92	*
Time of Day for Testing (hh:mm)		*			*
Dart Test Specimen Type	Square 6x6 in	*	Square 6x6 in	Square 6x6 in	*
IMPACT SIDE	Cavity	*	Core	Core	*
WEIGHT (lbs.)	67	*	67.00	67.00	*
HEIGHT (ft.)	21.5	*	21.50	21.50	*
ENERGY (ft-lbs)	1440.5	*	1440.5	1440.5	*
RESULT	Ductile	*	Ductile	Ductile	*
COMMENTS	20-Apr-92	*			*
		*			*
Dart coupon B table descriptor	DART SPEC B	*	DART SPEC B	DART SPEC B	*
		*			*
		*			*
TEST DATE (dd-mmm-yy)	20-Apr-92	*	20-Apr-92	20-Apr-92	*
Time of Day for Testing (hh:mm)		*			*
Dart Test Specimen Type	Square 6x6 in	*	Square 6x6 in	Square 6x6 in	*
IMPACT SIDE	Core	*	Cavity	Cavity	*
WEIGHT (lbs.)	67	*	67	67	*
HEIGHT (ft.)	21.5	*	21.5	21.5	*
ENERGY (ft-lbs)	1440.5	*	1440.5	1440.5	*
RESULT	Ductile	*	Ductile	**FAILED w/bulge**	*
COMMENTS	20-Apr-92	*			*
		*			*
Dart coupon C table descriptor	DART SPEC C	*	DART SPEC C	DART SPEC C	*
		*			*
		*			*
TEST DATE (dd-mmm-yy)	20-Apr-92	*	20-Apr-92	20-Apr-92	*
Time of Day for Testing (hh:mm)		*			*
Dart Test Specimen Type	Square 6x6 in	*	Square 6x6 in	Square 6x6 in	*
IMPACT SIDE	Cavity	*	Core	Core	*
WEIGHT (lbs.)	67	*	67	67	*
HEIGHT (ft.)	21.5	*	21.5	21.5	*
ENERGY (ft-lbs)	1440.5	*	1440.5	1440.5	*
RESULT	Ductile	*	Ductile	**FAILED w/bulge**	*
COMMENTS	20-Apr-92	*		Large brown Defect	*
		*			*
Dart coupon D table descriptor	DART SPEC D	*	DART SPEC D	DART SPEC D	*
		*			*
		*			*
TEST DATE (dd-mmm-yy)	20-Apr-92	*	20-Apr-92	20-Apr-92	*
Time of Day for Testing (hh:mm)		*			*
Dart Test Specimen Type	Square 6x6 in	*	Square 6x6 in	Square 6x6 in	*
IMPACT SIDE	Core	*	Cavity		*
WEIGHT (lbs.)	67	*	67		*
HEIGHT (ft.)	21.5	*	21.5		*
ENERGY (ft-lbs)	1440.5	*	1440.5		*
RESULT	Ductile	*	Ductile	Not tested	*
COMMENTS	20-Apr-92	*		Lg. Brown Defect	*
		*			*
**	*****************	*	*****************	*****************	*
GENERAL DART TEST COMMENTS: control (7/16 in ex					

streak in it, possibly indicating degraded material. The two failed 1/2-inch Dow 300-15 coupons came from the starboard side of the panel with the longest filling time of that group.

2.3.3 Coupon Measurements

Micrometer readings were taken on drop dart coupons for real time thickness results and because these panels would not be included in the pool from which to dimensionally map. The accuracy of the micrometer measurements was determined to be ±0.001 inch.

The micrometer readings were taken at the four corners of the dart coupons and at the midpoint of the edges of the coupons for a total of eight readings per coupon. The readings were taken approximately 1/2 inch from the external edges of the coupons. Figure 12 shows the approximate locations of the micrometer readings, and the results are presented in Table 5.

The results of the thickness measurements indicated several trends. For all flat panels measured the gate end of the panel was thicker than the arch end by 0.015 - 0.025 inch. This trend of greater thickness toward the gate also occurred in measurements taken at the opposite ends of the individual coupons.

For the 3/4-inch panels the results indicated that thickness increased as MFI decreased. Looking at the extremes, the Dow 300-4 coupons were approximately 0.003 inch thicker than Dow 300-15 coupons. For the 1/2-inch panels a similar, but opposite, trend occurred; the thickness decreased as the MFI decreased. The Dow 300-4 coupons were approximately 0.002 inch thinner than the Dow 300-15 coupons.

For a given location on particular coupons (i.e., top corner, inside edge, all A coupons), the range of thicknesses (max - min) did not exceed 0.005 inch for the 3/4-inch panels. The range for the 1/2-inch panels was 0.004 inch, with one exception. Panel MX2054 920415-08 (a 1/2-inch Dow XU7-5.5) was consistently 0.004-0.007 inch thinner than the other 1/2-inch panels. The reason for this is undetermined.

Table 5. Drop Dart Coupon Thickness Measurements

S-92 Molding; Envirotech;							
Salt Lake; UT April 1992	FIVR 3/4 in FLAT PANELS		~~~~~~~~~~~~	FIVR 1/2 in FLAT F~~~~~~~~~~		~~~~~~~~~~~~	~~~~~~~~~~~~
see note for cell A3							
RESIN TYPE	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-15	Dow 300-6	Dow 300-6
PROCESS NUMBER	MX2049	MX2049	MX2049	MX2053	MX2053	MX2052	MX2052
PANEL I.D. (YYMMDD-##)	920413-03	920413-04	920413-06	920414-03	920414-07	920414-02	920414-08
PANEL TYPE	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in
DART TEST DATA:							
	Panel Not Packed						
Dart coupon A table descriptor	DART SPEC A	DART SPEC A	DART SPEC A	DART SPEC A	DART SPEC A	DART SPEC A	DART SPEC A
Thickness: outside edge; top corner (gate end)	0.736	0.765	0.763	0.515	0.514	0.514	0.514
Thickness: outside edge; mid side	0.735	0.761	0.759	0.510	0.509	0.509	0.509
Thickness: outside edge; bottom corner	0.732	0.759	0.760	0.507	0.506	0.506	0.506
Thickness: inside edge; top corner (gate end)	0.736	0.763	0.762	0.514	0.513	0.513	0.512
Thickness: inside edge; mid side	0.730	0.759	0.758	0.509	0.508	0.507	0.507
Thickness: inside edge; bottom corner		0.759	0.760	0.507	0.505	0.505	0.505
Thickness: top edge; mid side (gate end)	0.733	0.763	0.761	0.515	0.513	0.513	0.512
Thickness: bottom edge; mid side	0.735	0.759	0.760	0.506	0.505	0.505	0.504
Dart coupon B table descriptor	DART SPEC B	DART SPEC B	DART SPEC B	DART SPEC B	DART SPEC B	DART SPEC B	DART SPEC B
Thickness: outside edge; top corner (gate end)	0.736	0.767	0.765	0.517	0.516	0.515	0.516
Thickness: outside edge; mid side	0.735	0.762	0.762	0.512	0.511	0.511	0.510
Thickness: outside edge; bottom corner	0.738	0.762	0.762	0.509	0.508	0.508	0.508
Thickness: inside edge; top corner (gate end)	0.730	0.763	0.762	0.515	0.513	0.513	0.512
Thickness: inside edge; mid side	0.732	0.759	0.758	0.509	0.508	0.508	0.507
Thickness: inside edge; bottom corner	0.745	0.759	0.760	0.506	0.506	0.506	0.505
Thickness: top edge; mid side (gate end)	0.735	0.765	0.764	0.516	0.515	0.515	0.514
Thickness: bottom edge; mid side	0.747	0.761	0.761	0.508	0.507	0.507	0.506
Dart coupon C table descriptor	DART SPEC C	DART SPEC C	DART SPEC C	DART SPEC C	DART SPEC C	DART SPEC C	DART SPEC C
Thickness: outside edge; top corner (gate end)	0.746	0.780	0.779	0.530	0.529	0.529	0.529
Thickness: outside edge; mid side	0.742	0.774	0.773	0.525	0.524	0.523	0.525
Thickness: outside edge; bottom corner	0.737	0.768	0.766	0.519	0.519	0.518	0.519
Thickness: inside edge; top corner (gate end)	0.745	0.778	0.777	0.528	0.527	0.527	0.528
Thickness: inside edge; mid side	0.737	0.773	0.770	0.523	0.522	0.522	0.523
Thickness: inside edge; bottom corner	0.732	0.765	0.763	0.517	0.516	0.515	0.515
Thickness: top edge; mid side (gate end)	0.746	0.779	0.778	0.529	0.528	0.528	0.529
Thickness: bottom edge; mid side	0.735	0.766	0.765	0.518	0.517	0.517	0.518
Dart coupon D table descriptor	DART SPEC D	DART SPEC D	DART SPEC D	DART SPEC D	DART SPEC D	DART SPEC D	DART SPEC D
Thickness: outside edge; top corner (gate end)	0.745	0.780	0.777	0.529	0.528	0.525	0.529
Thickness: outside edge; mid side	0.742	0.774	0.771	0.523	0.522	0.523	0.523
Thickness: outside edge; bottom corner	0.736	0.766	0.764	0.517	0.517	0.517	0.517
Thickness: inside edge; top corner (gate end)	0.745	0.778	0.777	0.528	0.527	0.527	0.527
Thickness: inside edge; mid side	0.738	0.773	0.770	0.522	0.521	0.522	0.522
Thickness: inside edge; bottom corner	0.732	0.764	0.763	0.516	0.516	0.516	0.516
Thickness: top edge; mid side (gate end)	0.745	0.778	0.776	0.528	0.528	0.528	0.527
Thickness: bottom edge; mid side			0.762	0.516	0.515	0.516	0.519

GENERAL DART TEST COMMENTS: control (7/16 in extruded polycarbonate) sample ductile when impacted by 47 lb dart dropped from 15 feet (1445.5 ftlb = 67lbs*21.5ft)

Table 5. Drop Dart Coupon Thickness Measurements (continued)

S-92 Molding; Envirotech;							
Salt Lake; UT April 1992							
see note for cell A3	------------	------------	FIVR 3/4 in FLAT F------------		FIVR 1/2 in FLAT F------------		FIVR 1/2 in FLAT F
RESIN TYPE							
PROCESS NUMBER	Dow 300-6	Dow 300-6	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	DOW XU73093.00L	DOW 300-4
PANEL I.D. (YYMMDD-##)	MX2048	MX2048	MX2050	MX2050	MX2054	MX2054	MX2051
PANEL TYPE	920414-2	920414-06	920415-03	920415-08	920415-03	920415-08	920415-03
	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in
************************************	******************	******************	******************	******************	******************	******************	******************
DART TEST DATA:							
Dart coupon A table descriptor	DART SPEC A	DART SPEC A	DART SPEC A	DART SPEC A	DART SPEC A	DART SPEC A	DART SPEC A
Thickness: outside edge; top corner (gate end)	0.767	0.766	0.766	0.765	0.514	0.508	0.513
Thickness: outside edge; mid side	0.763	0.760	0.761	0.760	0.509	0.505	0.508
Thickness: outside edge; bottom corner	0.759	0.758	0.758	0.757	0.505		0.505
Thickness: inside edge; top corner (gate end)	0.765	0.764	0.765	0.763	0.513	0.507	0.512
Thickness: inside edge; mid side	0.760	0.758	0.759	0.758	0.508	0.504	0.507
Thickness: inside edge; bottom corner	0.758	0.757	0.757	0.756	0.504		0.504
Thickness: top edge; mid side (gate end)	0.765	0.765	0.764	0.764	0.513		0.513
Thickness: bottom edge; mid side	0.757	0.757	0.757	0.756	0.504		0.504
Dart coupon B table descriptor	DART SPEC B	DART SPEC B	DART SPEC B	DART SPEC B	DART SPEC B	DART SPEC B	DART SPEC B
Thickness: outside edge; top corner (gate end)	0.768	0.767	0.768	0.767	0.515	0.510	0.516
Thickness: outside edge; mid side	0.764	0.763	0.762	0.762	0.511	0.507	0.510
Thickness: outside edge; bottom corner	0.761	0.760	0.760	0.760	0.508		0.508
Thickness: inside edge; top corner (gate end)	0.765	0.764	0.764	0.763	0.512	0.507	0.512
Thickness: inside edge; mid side	0.760	0.759	0.759	0.758	0.508	0.504	0.507
Thickness: inside edge; bottom corner	0.758	0.757	0.757	0.756	0.505		0.504
Thickness: top edge; mid side (gate end)	0.767	0.766	0.767	0.765	0.514		0.515
Thickness: bottom edge; mid side	0.761	0.759	0.758	0.758	0.506		0.507
Dart coupon C table descriptor	DART SPEC C	DART SPEC C	DART SPEC C	DART SPEC C	DART SPEC C	DART SPEC C	DART SPEC C
Thickness: outside edge; top corner (gate end)	0.782	0.782	0.782	0.781	0.529	0.524	0.529
Thickness: outside edge; mid side	0.776	0.777	0.776	0.775	0.524	0.518	0.524
Thickness: outside edge; bottom corner	0.770	0.770	0.770	0.769	0.518		0.518
Thickness: inside edge; top corner (gate end)	0.781	0.780	0.780	0.779	0.527	0.521	0.527
Thickness: inside edge; mid side	0.774	0.773	0.774	0.772	0.522	0.515	0.522
Thickness: inside edge; bottom corner	0.767	0.766	0.767	0.766	0.516		0.515
Thickness: top edge; mid side (gate end)	0.781	0.781	0.781	0.780	0.528		0.528
Thickness: bottom edge; mid side	0.769	0.768	0.768	0.767	0.517		0.517
Dart coupon D table descriptor	DART SPEC D	DART SPEC D	DART SPEC D	DART SPEC D	DART SPEC D	DART SPEC D	DART SPEC D
Thickness: outside edge; top corner (gate end)	0.781	0.781	0.781	0.780	0.528	0.523	0.528
Thickness: outside edge; mid side	0.775	0.774	0.774	0.773	0.523	0.516	0.522
Thickness: outside edge; bottom corner	0.769	0.768	0.768	0.767	0.517		0.516
Thickness: inside edge; top corner (gate end)	0.780	0.781	0.780	0.779	0.527	0.521	0.527
Thickness: inside edge; mid side	0.773	0.773	0.772	0.773	0.522	0.515	0.521
Thickness: inside edge; bottom corner	0.767	0.767	0.767	0.766	0.515		0.515
Thickness: top edge; mid side (gate end)	0.781	0.781	0.780	0.779	0.527		0.527
Thickness: bottom edge; mid side	0.768	0.767	0.766	0.766	0.515		0.515
************************************	******************	******************	******************	******************	******************	******************	******************
GENERAL DART TEST COMMENTS: control (7/16 in ex							

Table 5. Drop Dart Coupon Thickness Measurements (concluded)

S-92 Molding; Envirotech;		*			*
Salt Lake; UT April 1992	~~~~~~~~~~~~	*	~~~~~~~~~~~~	~~~~~~~~~~~~	*
see note for cell A3		*			*
RESIN TYPE	DOW 300-4	*	DOW 300-4	DOW 300-4	*
PROCESS NUMBER	MX2051	*	MX2047	MX2047	*
PANEL I.D. (YYMMDD-##)	920415-08	*	920416-02	920416-09	*
PANEL TYPE	Flat - 1/2 in	*	Flat - 3/4 in	Flat - 3/4 in	*
**	*****************	*	*****************	*****************	*
DART TEST DATA:		*			*
		*			*
Dart coupon A table descriptor	DART SPEC A	*	DART SPEC A	DART SPEC A	*
		*			*
Thickness: outside edge; top corner (gate end)	0.513	*	0.766	0.765	*
Thickness: outside edge; mid side	0.508	*	0.762	0.761	*
Thickness: outside edge; bottom corner	0.504	*	0.758	0.757	*
Thickness: inside edge; top corner (gate end)	0.512	*	0.765	0.763	*
Thickness: inside edge; mid side	0.506	*	0.760	0.758	*
Thickness: inside edge; bottom corner	0.504	*	0.757	0.756	*
Thickness: top edge; mid side (gate end)	0.512	*	0.765	0.763	*
Thickness: bottom edge; mid side	0.503	*	0.757	0.755	*
		*			*
		*			*
		*			*
Dart coupon B table descriptor	DART SPEC B	*	DART SPEC B	DART SPEC B	*
		*			*
Thickness: outside edge; top corner (gate end)	0.515	*	0.768	0.767	*
Thickness: outside edge; mid side	0.510	*	0.763	0.762	*
Thickness: outside edge; bottom corner	0.507	*	0.761	0.760	*
Thickness: inside edge; top corner (gate end)	0.512	*	0.765	0.762	*
Thickness: inside edge; mid side	0.507	*	0.760	0.758	*
Thickness: inside edge; bottom corner	0.504	*	0.757	0.756	*
Thickness: top edge; mid side (gate end)	0.514	*	0.767	0.765	*
Thickness: bottom edge; mid side	0.505	*	0.760	0.757	*
		*			*
		*			*
		*			*
Dart coupon C table descriptor	DART SPEC C	*	DART SPEC C	DART SPEC C	*
		*			*
Thickness: outside edge; top corner (gate end)	0.528	*	0.782	0.780	*
Thickness: outside edge; mid side	0.523	*	0.777	0.776	*
Thickness: outside edge; bottom corner	0.517	*	0.771	0.769	*
Thickness: inside edge; top corner (gate end)	0.526	*	0.780	0.779	*
Thickness: inside edge; mid side	0.521	*	0.776	0.773	*
Thickness: inside edge; bottom corner	0.515	*	0.768	0.766	*
Thickness: top edge; mid side (gate end)	0.528	*	0.782	0.780	*
Thickness: bottom edge; mid side	0.516	*	0.770	0.767	*
		*			*
		*			*
		*			*
Dart coupon D table descriptor	DART SPEC D	*	DART SPEC D	DART SPEC D	*
		*			*
Thickness: outside edge; top corner (gate end)	0.528	*	0.781	0.779	*
Thickness: outside edge; mid side	0.522	*	0.776	0.774	*
Thickness: outside edge; bottom corner	0.516	*	0.769	0.767	*
Thickness: inside edge; top corner (gate end)	0.526	*	0.780	0.778	*
Thickness: inside edge; mid side	0.520	*	0.776	0.773	*
Thickness: inside edge; bottom corner	0.514	*	0.768	0.766	*
Thickness: top edge; mid side (gate end)	0.527	*	0.781	0.779	*
Thickness: bottom edge; mid side	0.514	*	0.768	0.765	*
		*			*
		*			*
**	*****************	*	*****************	*****************	*
GENERAL DART TEST COMMENTS: control (7/16 in ex					

One panel (MX2049 920413-01, a 3/4-inch Dow 300-15) was not packed during the molding cycle. The thickness results show the unpacked coupons to be on the order of 0.030 inch thinner than packed coupons.

2.4 Conclusions

2.4.1 Capabilities for Molding Panels

Molding the range of MFIs in the desired panel configurations presented no problems. Also, molding flat panels 3/4 inch thick presented no difficulties. No evidence was found in the molding or on-site testing to suggest that the properties of 3/4-inch panels were degraded relative to those of 1/2-inch panels.

Some minor difficulties were encountered in the molding process. For example, the occurrence of black specks and debris in the molded panels increased as molding progressed. This required some purging of material and finessing of the accumulator resin level by the Envirotech process engineer. Additionally, some minor equipment breakdowns occurred that delayed molding temporarily.

2.4.2 Effects of Melt Flow Index

2.4.2.1 On Molding Parameters

SCREW SPEED - As the MFI decreased, the screw speed used also decreased. This was done to allow efficient resin melting without resin degradation. The shearing action of the screw combines with the heaters in the extruder barrel to melt the resin pellets. A balance between the energy required by the heaters, the energy required by the screw, and the potential resin degradation caused by excessive screw speed is obtained based on resin vendor recommendations and molder experience. The slower screw speed (30 RPM) used for the Dow 300-4 (high viscosity) could have been used for the Dow 300-15 (low viscosity), but then the heaters would have had to input more energy to reach the desired melt temperature.

Additionally, the faster screw speed (40-50 rpm) used for the Dow 300-15 could have been used for the Dow 300-4, but resin degradation might have occurred.

MOLD FILL TIME - The time required to fill the mold increased as the MFI decreased. Since the same injection pressure was used throughout the subject molding trials, it was concluded that the more viscous resin flowed more slowly into the mold.

The cone data suggest that the mold fill time decreased as the melt temperature increased. The higher the temperature, the less viscous the resin, and the resin flowed more quickly.

MELT TEMPERATURE - A meaningful conclusion concerning melt temperature cannot be drawn due to unreliable temperature data. Resin vendor data and molder experience are both considered in determining a desired melt temperature. Heaters are set and adjusted in order to obtain the desired melt temperature. However, for this subject molding (as in all previous panel molding), **a dependable method for measuring the temperature of the resin entering the mold DID NOT exist.** The melt temperature data recorded and presented should be viewed with this serious caveat in mind.

A review of the original process sheets does show a trend which indicates, for the same nozzle tip temperature setting, a higher actual nozzle tip temperature for the high viscosity resin than for the low viscosity resin. The 3/4-inch Dow 300-15 panels had an average actual nozzle tip temperature of 565°F, while the 3/4-inch Dow 300-4 panels had an average actual nozzle tip temperature of 584°F. The set nozzle tip temperature for both sets of panels was 570°F. The 1/2-inch Dow 300-15 panels had an average actual nozzle tip temperature of 563°F, while the 1/2-inch Dow 300-4 panels had an average actual nozzle tip temperature of 572°F. The set nozzle tip temperature for both sets of panels was 570°F.

2.4.2.2 On Panel Quality

Considering both 1/2-inch and 3/4-inch flat panels, there is no question that the experimental resin, Dow XU7-5.5, produced the best quality panel. However, the same resin produced the lowest quality cones. In the cones problems with surface splay, orange peel, and dark streaks were common with XU7-5.5, while minimal with the other resins. No definitive reason for this can be offered; however, the cone mold does have a history of inconsistent molding "behavior."

Only one trend was identified that associated an individual panel quality indicator with varying MFI. Thickened edge sink became more pronounced as the MFI decreased. This indicates that parts made with a lower MFI resin (more viscous resin) are more difficult to pack completely.

2.4.2.3 On Dimensional Variance and Shrinkage

No meaningful conclusion can be drawn concerning the effect of MFI on shrinkage based on micrometer measurements of drop dart coupon thicknesses. The 3/4 inch-panels indicated that as MFI decreased, shrinkage decreased, while the 1/2-inch panels indicated the opposite; as MFI decreased, shrinkage increased. Also, the trends are very subtle; the maximum difference in shrinkage for the -15 MFI vs. the -4 MFI was only 0.003 inch. The section of this report dealing with dimensional mapping describes shrinkage more completely and accurately.

An additional note is in order here. The maximum range of thickness measurements (0.005 inch) indicates that the panel molding produced very repeatable parts.

2.4.2.4 On Impact Resistance

The effect of the MFIs on impact resistance were hard to quantify since only 6 of 67 coupons failed. Three of the failures were from Dow 300-15, one from Dow 300-6,

and the two from Dow 300-4 came from a panel of possibly degraded resin. No complete coupon failures occurred in panels molded from Dow XU7-5.5. The conclusion is that as MFI increases, impact resistance decreases. It should be noted that this conclusion is based on a limited number of tests, all but one of which were performed at the maximum capacity of the equipment available.

2.4.3 Effects of Thickness

2.4.3.1 On Molding Parameters

No unexpected changes in molding parameters resulted from the increase in flat panel thickness from 1/2 to 3/4 inch. Of course, more resin was required to fill the 3/4-inch mold which resulted in a longer filling time. The additional resin required also took longer to extrude into the accumulator, and this resulted in a longer total cycle time and a longer melt residency time. Injection pressure, melt temperature, packing pressure, and pack time all remained the same as in the 1/2-inch panel molding. No molding parameter problems surfaced as a result of the increased thickness.

2.4.3.2 On Panel Quality

The 1/2-inch panels scored slightly higher in overall quality (influenced mostly by surface splay, bubbles and voids, and orange peel) than the 3/4-inch panels. Although it is possible that increased thickness inherently caused problems, it is more likely that some processing parameters could have been adjusted to produce 3/4-inch panels with quality consistently as good as that of the 1/2-inch panels. For example, the injection speed was not changed when the mold thickness was changed. A slower (or faster) injection speed may have produced 3/4-inch panels with less surface splay and orange peel. Other parameters that may have been applicable to change were injection pressure, packing pressure, melt temperature, and mold temperature.

2.4.3.3 On Dimensional Variance and Shrinkage

The 3/4-inch panels exhibited a larger range of thickness variance than the 1/2-inch panels. However, since the units of shrinkage are inch/inch, the larger range was expected.

The 3/4-inch panels also have less thickened edge sink than the 1/2-inch panels. This indicates that the edges packed better in the thicker panels, possibly because the larger volume of the 3/4-inch mold allowed a more effective packing path than the 1/2-inch mold.

2.4.3.4 On Impact Resistance

The only noticeable effect that increased thickness had on drop dart impact resistance was that the 3/4-inch coupons had less permanent deformation than the 1/2-inch coupons. Drop dart tests were performed on 67 coupons, and 6 coupons failed. Although half of the failures were from 3/4-inch coupons, all three came from panels that had a severe flaw, either major surface splay or a large dark streak. The drop dart impact tests indicated that the 3/4-inch panels were consistently tougher than the 1/2-inch panels. However, this conclusion is based on a limited number of tests, all but one of which were performed at the maximum capacity of the equipment available.

SECTION 3
DIMENSIONAL MAPPING

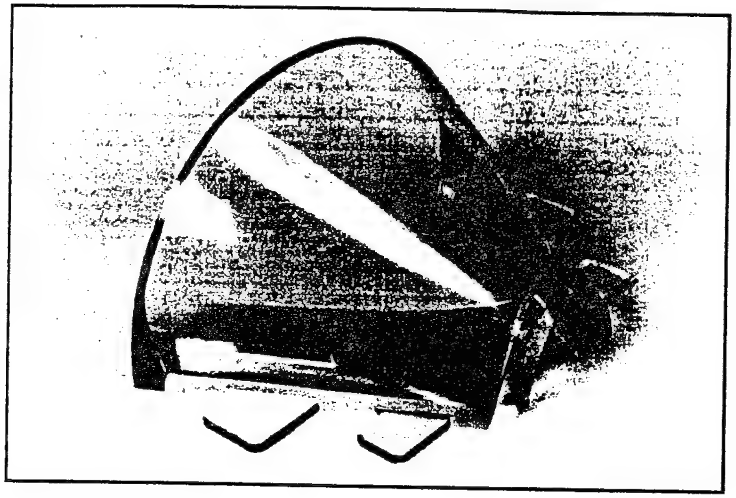
3.1 Introduction

One of the many objectives of the Frameless Transparency Program (FTP) is to demonstrate that improvements in optical quality can be achieved in injection molded transparencies. Since thickness changes directly affect optical distortion and angular deviation, knowing as much as possible about the thickness distributions of the molds and panels is important. Directly related to thickness distribution is the shrinkage that occurs through the thickness as the molded panel cools and solidifies. Another objective of the FTP is to further investigate and quantify the shrinkage characteristics of injection molded panels and to evaluate the need for designing for potentially nonuniform shrinkage factors in future transparency molds. An additional objective of the FTP is to demonstrate that transparencies can be consistently fabricated with the same dimensions using the injection molding process. In support of meeting these objectives for the FTP, 39 panels and 3 molds were dimensionally mapped under this effort. The dimensional mapping (DM) portion of the effort was performed at Giddings & Lewis Measurement Systems, Dayton, Ohio, using a high accuracy coordinate measuring machine (CMM). This section presents a background on molded panels, a description of dimensional mapping, and the objectives and scope of the DM effort. A detailed description of the DM facilities, setup, and procedures follows in Section 3.2. Finally, the DM results and conclusions are presented in Section 3.3.

3.1.1 Background

In support of the FTP, hundreds of flat and conical panels (Figure 13) were injection molded at Envirotech Molded Products, Salt Lake City, Utah, and at Hettinga Equipment Corporation, Des Moine, Iowa. Panels were molded using several different materials and a wide variety of processing parameters (temperatures, pressures, shot size, cycle times, etc.). Panels with desirable characteristics were typically molded from clear polycarbonate at an injection pressure of approximately 750 psi and with a cycle time of approximately 30 minutes.

DIRECTLY FORMED FRAMELESS AIRCRAFT TRANSPARENCIES
PROCESS DEVELOPMENT PANELS



Conical Panel

1/2 in thick

2 in thickened edges

Flat Panel

1/2 and 3/4 in thick

2 in thickened edges

Simulated Juncture

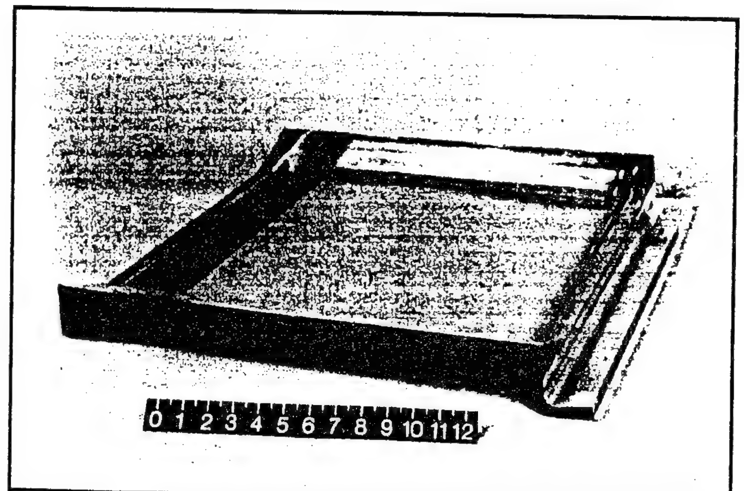


Figure 13. Conical and Flat Panels

One of the tests done on some of these molded panels was dimensional mapping. The term "dimensional mapping" was coined by WL/FIVR because a description, or mapping, of the overall dimension and the thickness distribution of the panels and their molds was required. "Dimensional Mapping" (DM) seemed to describe the whole exercise nicely. The first DM effort by WL/FIVR took place in 1991 on flat and conical panels molded in different sessions between 1988 and 1990. The 1992 dimensional mapping in this effort was based on procedures developed and results obtained during the 1991 DM effort. Both efforts were performed at Giddings and Lewis Measurement Systems (formerly Sheffield Measurement Systems) in Dayton, Ohio.

During the 1991 DM effort 4 conical panels, 13 flat panels, and a conical and flat panel mold were dimensionally mapped. The data obtained from the 1991 DM effort revealed a nonuniform shrinkage in the molded panels and led to the application of a shrinkage compensation factor to the CFT mold design.

The panels dimensionally mapped in 1991 were left over from previous molding and testing sessions. The 1991 DM effort was not anticipated when those panels were molded or tested, so the availability of panels was limited for the 1991 DM effort. The 1991 DM data were useful; however, the population of panels was small, the panels were molded from a variety of materials, and the panels were molded at two different molding locations using two different gating arrangements. In order to gain a further understanding of the dimensional characteristics of molded panels, a set of panels molded under a consistent set of conditions was required.

In March, 1992, the Air Force initiated this subject effort to mold conical and flat panels and to perform birdstrike testing, materials testing, and dimensional mapping on the panels. The intent of the molding trials was to mold and evaluate all panels from four different melt flow indexes of the same class of resin, Dow Calibre 300. The actual resins used were: Dow 300-4, Dow 300-6, Dow 300-15, and an experimental resin, Dow XU73093.00L-5.5. Since the requirement for dimensional mapping was included in this effort, all panels were potentially available for the DM portion of the effort, thereby providing a more consistent population from which to choose the panels for mapping.

3.1.2 Objectives.

The objectives for the dimensional mapping portion of the effort were:

a) To investigate the effect of different MFIs on panel shrinkage.

b) To increase the population of parts for which DM data were available.

c) To compare 1992 DM data and results with 1991 DM data and results.

d) To further study shrinkage effects and their application to the CFT and the CFT mold.

e) To contribute to the formulation of procedures to dimensionally map the CFT and CFT mold.

3.1.3 Scope

The panels molded in April, 1992, can be categorized into 12 different groups; 1/2-inch thick flat panels from each of the 4 resins, 3/4-inch thick flat panels from each of the 4 resins, and 1/2-inch thick conical panels from each of the 4 resins. A list of the panels dimensionally mapped is given in Table 6.

Three fully packed panels from each of the 12 groups were dimensionally mapped, as well as 1 unpacked cone from 3 of the 4 groups of cones, for a total of 39 panels. The dimensionally mapped panels from each group were molded using similar molding process parameters. The molding parameters and panel evaluations are shown in Table 7.

The molds for the panels were also dimensionally mapped, and the differences between mold data and panel data were used to calculate shrinkage values. A technique for relating the data from one mold half to another using precision ground tooling spheres was also developed.

The acquired data were used to obtain an accurate description of the thickness distribution of the molded panels. The data were also used to calculate a limited number of overall dimensions at several discrete locations. The scope of this effort did <u>not</u> include

Table 6. Molded Panels for Dimensional Mapping - April 1992.

	Proc #	Panel ID	Material	Part Description	DOS Filename
1	MX2047	920416-04	DOW 300-04	3/4" FLAT PANEL	MX204704.P04
2	MX2047	920416-05	DOW 300-04	3/4" FLAT PANEL	MX204705.P04
3	MX2047	920416-08	DOW 300-04	3/4" FLAT PANEL	MX204708.P04
4	MX2050	920415-04	DOW XU7-5.5	3/4" FLAT PANEL	MX205004.P55
5	MX2050	920415-05	DOW XU7-5.5	3/4" FLAT PANEL	MX205005.P55
6	MX2050	920415-06	DOW XU7-5.5	3/4" FLAT PANEL	MX205006.P55
7	MX2048	920414-03	DOW 300-06	3/4" FLAT PANEL	MX204803.P06
8	MX2048	920414-05	DOW 300-06	3/4" FLAT PANEL	MX204805.P06
9	MX2048	920414-07	DOW 300-06	3/4" FLAT PANEL	MX204807.P06
10	MX2049	920413-03	DOW 300-15	3/4" FLAT PANEL	MX204903.P15
11	MX2049	920413-08	DOW 300-15	3/4" FLAT PANEL	MX204908.P15
12	MX2049	920413-09	DOW 300-15	3/4" FLAT PANEL	MX204909.P15
13	MX2051	920415-04	DOW 300-04	1/2" FLAT PANEL	MX205104.P04
14	MX2051	920415-05	DOW 300-04	1/2" FLAT PANEL	MX205105.P04
15	MX2051	920415-07	DOW 300-04	1/2" FLAT PANEL	MX205107.P04
16	MX2054	920415-04	DOW XU7-5.5	1/2" FLAT PANEL	MX205404.P55
17	MX2054	920415-05	DOW XU7-5.5	1/2" FLAT PANEL	MX205405.P55
18	MX2054	920415-06	DOW XU7-5.5	1/2" FLAT PANEL	MX205406.P55
19	MX2052	920414-04	DOW 300-06	1/2" FLAT PANEL	MX205204.P06
20	MX2052	920414-05	DOW 300-06	1/2" FLAT PANEL	MX205205.P06
21	MX2052	920414-07	DOW 300-06	1/2" FLAT PANEL	MX205207.P06
22	MX2053	920414-04	DOW 300-15	1/2" FLAT PANEL	MX205304.P15
23	MX2053	920414-06	DOW 300-15	1/2" FLAT ANEL	MX205306.P15
24	MX2053	920414-08	DOW 300-15	1/2" FLAT PANEL	MX205308.P15
25	MX2055	920422-01	DOW 300-04	1/2" CONE	MX205501.C04
26	MX2055	920422-02	DOW 300-04	1/2" CONE	MX205502.C04
27	MX2055	920422-04	DOW 300-04	1/2" CONE	MX205504.C04
28	MX2055	920422-05	DOW 300-04	1/2" CONE	MX205505.C04
29	MX2058	920421-01	DOW XU7-5.5	1/2" CONE	MX205801.C55
30	MX2058	920421-03	DOW XU7-5.5	1/2" CONE	MX205803.C55
31	MX2058	920421-04	DOW XU7-5.5	1/2" CONE	MX205804.C55
32	MX2058	920421-05	DOW XU7-5.5	1/2" CONE	MX205805.C55
33	MX2056	920421-01	DOW 300-06	1/2" CONE	MX205601.C06
34	MX2056	920421-03	DOW 300-06	1/2" CONE	MX205603.C06
35	MX2056	920421-04	DOW 300-06	1/2" CONE	MX205604.C06
36	MX2056	920421-05	DOW 300-06	1/2" CONE	MX205605.C06
37	MX2057	920421-05	DOW 300-15	1/2" CONE	MX205705.C15
38	MX2057	920421-06	DOW 300-15	1/2" CONE	MX205706.C15
39	MX2057	920421-07	DOW 300-15	1/2" CONE	MX205707.C15

Table 7. Molding and Evaluation Data For Dimensionally Mapped Panels

RESIN TYPE	DOW 300-4	DOW 300-4	DOW 300-4	DOW XU7-5.5	DOW XU7-5.5	DOW XU7-5.5	Dow 300-6	Dow 300-6	Dow 300-6	Dow 300-15	Dow 300-15	Dow 300-15	DOW 300-4	DOW 300-4
PROCESS NUMBER	MX2047	MX2047	MX2047	MX2050	MX2050	MX2050	MX2048	MX2048	MX2048	MX2049	MX2049	MX2049	MX2051	MX2051
PANEL I.D. (YYMMDD-##)	920416-04	920416-05	920416-08	920415-04	920415-05	920415-06	920414-03	920414-05	920414-07	920413-07	920413-08	920413-09	920415-04	920415-05
PANEL TYPE	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 3/4 in	Flat - 1/2 in	Flat - 1/2 in
MOLDING PARAMETERS:														
RESIN DRY TIME (HRS)														
ACCUMULATE TIME (min)							26.00	26.00	26.00	26.00	26.00	26.00		
ACCUMULATE QUANTITY (piston pos inches)	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00		
ACCUMULATOR PURGE (before/after fill)							b	b	b					
TOD - NOZZLE IN; VALVE ROTATION	11:15	12:15	15:20	11:45	13:05	14:10	0:30	2:40	4:30	22:20	23:20	0:20	2:45	3:30
FILLING TIME (seconds)	15.2	14.1	14.1	15.8	14.1	14.9	11.67	12.84	12.5	7.53	7.50	7.50	16.35	15 96
INJECT PRESSURE MAX (psi)	750	750	750	750	750	750	750	750	750	750	750	750		
PACKING PRESSURE (psi)	750	750	750	750	750	750	750	750	750	750	750	750		
TOD - MOLD OPEN	12:00	13:00	16:05	12:40	12:50	14:55	01:15	03:25	05:15	23:05	00:05	01:05	03:15	04:00
MOLD CAV TEMP; FILL (deg F)	208	209	209	207	207	207	208	210	214	204	210	214	213	214
MOLD CORE TEMP; FILL (deg F)	213	213	2213	210	211	211	211	214	219	204	212	217	219	219
MELT TEMP; NOZZLE TIP; FILL (deg F)	562	561	561	560	560	560	560	560	561	573	573	573	561	561
SCREW RPM				30	30	30	40			50	50	50	30	30
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.										improved purge; time delay due to change in accu hyd cylinder				
MOLDED PANEL CHARACTERISTICS:							3/4; 6 MFI	3/4; 6 MFI	3/4; 6 MFI	3/4; 15 MFI	3/4; 15 MFI	3/4; 15 MFI		
(eval code 1 good; 10 bad)														
WEIGHT (pounds)	29.56	29.56	29.69	29.63	29.56	29.56	29.63	29.56	29.63	29.63	29.63	29.63	22.69	22.69
OVERALL QUALITY	4	6	5	3	4	4	3	5	5	5	3	4	3	5
SURFACE SPLAY; STREAKING	1	6	6	5	5	5	3	5	6	5	2	3	1	3
THICKENED EDGE SINK	3	3	4	3	3	3	4	3	4	2	2	2	6	6
BUBBLES	9	3	2	2	1	2	2	3	2	7	4	1	2	4
VOIDS	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ORANGE PEEL	1	1	3	3	6	4	2	3	2	4	1	3	1	3
DARK STREAKS	4	4	4	3	2	1	3	2	2	3	3	4	2	3
DARK SPECKS DEBRIS	5	2	2	3	3	1	1	2	1	3	2	8	3	5
WELD LINE INTENSITY; DEPTH	1	1	1	1	1	1	1	2	1	1	1	1	1	1
BEST COLOR	BT	BT	BT	LA	LA	LA	WW	WW	WW	ww	ww	ww	BT	BT
WELD LINE JUNCTURE TO EDGE (inches)	OFF PANEL	OFF PANEL	OFF PANEL	OFF PART	OFF PART	OFF PART	OFF PANEL	OFF PANEL	OFF PANEL	off panel	off panel	off panel	1.13	1.13
WELD LINE JUNCT OFF CL (inches)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	n/a	n/a	n/a	3/8 S	7/16 S
WELD LINE JUNCT DEPTH (inches)	N/A	N/A	N/A	N/A	N/A	N/A	SURFACE	SURFACE	SURFACE	n/a	n/a	n/a	SURFACE	SURFACE
EVALUATION COMMENTS:										Rows of bubbles down sills	Best of 3/4" 15 panels		only one bubble	Defects mostly in sill edges
date code ==> yymmdd-panel number														
mold core - concve side of panels														
port side ==> left side when facing gate end from trailing edge with concave face up														
short shot ==> intentional injection of less material than required to fill mold														
units:														
temperatures - deg F														
length or distance - inches														
time - seconds (unless minutes indicated)														
pressure - psi														

Table 7. Molding and Evaluation Data For Dimensionally Mapped Panels (continued)

RESIN TYPE	DOW 300-4	DOW XU7-5.5	DOW XU7-5.5	DOW XU7-5.5	Dow 300-6	Dow 300-6	Dow 300-6	Dow 300-15	Dow 300-15	Dow 300-15	DOW 300-4	DOW 300-4	DOW 300-4	DOW 300-4
PROCESS NUMBER	MX2051	MX2054	MX2054	MX2054	MX2052	MX2052	MX2052	MX2053	MX2053	MX2053	MX2055	MX2055	MX2055	MX2055
PANEL I.D. (YYMMDD-##)	920415-07	920415-04	920415-05	920415-06	920414-04	920414-06	920414-07	920414-04	920414-06	920414-08	920422-01	920422-02	920422-04	920422-05
PANEL TYPE	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Flat - 1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in
MOLDING PARAMETERS:														
RESIN DRY TIME (HRS)														
ACCUMULATE TIME (min)								26.00	26.00	26.00				
ACCUMULATE QUANTITY (piston pos inches)								13.00	13.00	13.00	10.5	10.5	10.5	10.5
ACCUMULATOR PURGE (before/after fill)														
TOD - NOZZLE IN; VALVE ROTATION	5:15	20:00	20:45	21:25	17:40	19:15	20:00	9:15	11:25	13:00	8:20	9:05	10:35	12:05
FILLING TIME (seconds)	16.17	14.3	14.42	14.64	11.9	11.67	12.44	7.00	7.30	8.50	9.5	10.2	9.8	9.1
INJECT PRESSURE MAX (psi)		750	750	750	750	750	750	750	750	750	750	750	750	750
PACKING PRESSURE (psi)		750	750	750	750	750	750	750	750	750	750	750	750	750
TOD - MOLD OPEN	05:45	20:30	21:15	21:55	18:10	10:48	20:30	09:45	11:55	13:30	08:50	09:35	11:05	12:35
MOLD CAV TEMP; FILL (deg F)	213	211	210	213	216	216	214	209	208	211	164	168	174	172
MOLD CORE TEMP; FILL (deg F)	218	216	214	220	220	220	218	201	212	215	157	160	167	166
MELT TEMP; NOZZLE TIP; FILL (deg F)	560	560	561	560	560	560	560	550	560	560	574	572	572	573
SCREW RPM	30	30	30	320	40	40	40	50	50	50	30	30	30	30
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.											UN-PACKED			
MOLDED PANEL CHARACTERISTICS:					1/2; 6 MFI	1/2; 6 MFI	1/2; 6 MFI	1/2; 15 MFI	1/2; 15 MFI	1/2; 15 MFI				
(eval code 1 good; 10 bad)														
WEIGHT (pounds)	22.66	22.66	22.656	22.625	22.75	22.73	22.73	22.75	22.69	22.75	14.4375		14.4375	
OVERALL QUALITY	4	2	2	2	7	7	6	6	2	2	10	4	5	3
SURFACE SPLAY; STREAKING	1	1	1	1	7	4	3	6	1	1	4	2	1	1
THICKENED EDGE SINK	6	5	6	6	7	7	7	3	7	2		1	1	1
BUBBLES	4	2	2	2	7	9	7	3	1	4	1	1	1	1
VOIDS	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ORANGE PEEL	1	1	1	1	5	5	4	1	3	3	1	1	1	1
DARK STREAKS	2	1	1	1	1	3	2	2	5	5	3	1	1	1
DARK SPECKS DEBRIS	3	1	1	1	1	1	1	2	8	2	3	3	3	4
WELD LINE INTENSITY; DEPTH	1	1	1	1	7	7	5	1	3	2				
BEST COLOR	BT	A	A	A	WW	WW	WW	WW	WW	WW	BT	BT/Amber	Amber	BT
WELD LINE JUNCTURE TO EDGE (Inches)	1.13	1.0625	1.0625	1.0625	0.88	0.94	0.94	0.63	0.75	0.81				
WELD LINE JUNCT OFF CL (inches)	9/16 S	5/16 S	7/16 S	7/16 S	0.25	0.19	0.31	0.19	0.19	0.50				
WELD LINE JUNCT DEPTH (inches)	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE	SURFACE				
EVALUATION COMMENTS:									MAPPING; BI TEST	MAPPING; BI TEST	No Pack	material slightly overprocessed color going from BT to amber	overprocessed material	
date code ==> yymmdd-panel number														
mold core - concve side of panels														
port side ==> left side when facing gate end from t														
short shot ==> intentional injection of less material														
units:														
temperatures - deg F														
length or distance - inches														
time - seconds (unless minutes indicated)														
pressure - psi														

Table 7. Molding and Evaluation Data For Dimensionally Mapped Panels (concluded)

RESIN TYPE	DOW XU7-5.5	DOW XU7-5.5	DOW XU7-5.5	DOW XU7-5.5	DOW 300-6	DOW 300-6	DOW 300-6	DOW 300-6	DOW 300-15	DOW 300-15	DOW 300-15
PROCESS NUMBER	MX2058	MX2058	MX2058	MX2058	MX2056	MX2056	MX2056	MX2056	MX2057	MX2057	MX2057
PANEL I.D. (YYMMDD-##)	920421-01	920421-03	920421-04	920421-05	920421-01	920421-03	920421-04	920421-05	920421-05	920421-06	920421-07
PANEL TYPE	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone -1/2 in	Cone - 1/2 in	Cone - 1/2 in	Cone - 1/2 in
MOLDING PARAMETERS:											
RESIN DRY TIME (HRS)											
ACCUMULATE TIME (min)											
ACCUMULATE QUANTITY (piston pos inches)	10.5	10.5	10.5	10.5	10.5	10.5			10.5	10.5	10.5
ACCUMULATOR PURGE (before/after fill)							before 1/2 in	before 1/2 in			
TOD - NOZZLE IN; VALVE ROTATION	0:30	1:50	2:30	3:30	19:00	20:35	21:20	22:00	15:35	16:25	17:40
FILLING TIME (seconds)	7.41	8.27	8.23	8.3	6.9	9.76	9.19	9.56	5.5	4.9	6
INJECT PRESSURE MAX (psi)	750	750	750	750	750	750	750	750	750	750	750
PACKING PRESSURE (psi)	750	750	750	750	750	750	750	750	750	750	750
TOD - MOLD OPEN	01:00	02:20	03:00	04:00	19:30	21:05	21:50	22:30	16:05	16:55	17:40
MOLD CAV TEMP; FILL (deg F)	176	181	180	181	176	181	184	183	174	176	180
MOLD CORE TEMP; FILL (deg F)	170	176	174	175	170	174	175	175	166	170	173
MELT TEMP; NOZZLE TIP; FILL (deg F)	574	574	573	573	574	573	573	573	573	573	573
SCREW RPM	35	35	35	35	37	37	37	37	40	40	40
PROCESS COMMENTS Minor oil crazing; all panels. Melt temp reported was measured between extruder and accumulator; lower heating band sets were approximately this value.	UN-PACKED				UN-PACKED						
MOLDED PANEL CHARACTERISTICS:											
(eval code 1 good; 10 bad)											
WEIGHT (pounds)	14.375				14.1875						
OVERALL QUALITY	10	8	8	7	10	3	5	3	3	3	3
SURFACE SPLAY; STREAKING	2	7	7	6	3	1	3	2	1	1	1
THICKENED EDGE SINK		1	1	1	8	1	1	1	1	1	1
BUBBLES	2	1	1	2	5	1	1	1	1	1	1
VOIDS		1	1	1		1	1	1	1	1	1
ORANGE PEEL	1	1	3	3	1	1	1	1	1	1	1
DARK STREAKS	3	4	1	2	3	1	2	1	1	1	3
DARK SPECKS DEBRIS	1	2	3	5	4	1	3	1	3	2	1
WELD LINE INTENSITY; DEPTH											
BEST COLOR	Amber	Amber	Amber	Amber	ww	ww	ww	ww	ww	ww	ww
WELD LINE JUNCTURE TO EDGE (inches)											
WELD LINE JUNCT OFF CL (inches)											
WELD LINE JUNCT DEPTH (inches)											
EVALUATION COMMENTS:		Splay & streak of optical area			No pack	machine gate			Machine gate	Machice gate	
date code ==> yymmdd-panel number											
mold core - concve side of panels											
port side ==> left side when facing gate end from t											
short shot ==> intentional injection of less material											
units:											
temperatures - deg F											
length or distance - inches											
time - seconds (unless minutes indicated)											
pressure - psi											

calculating all panel dimensions and feature locations, such as those that would be found on an engineering drawing.

3.2 Dimensional Mapping Effort

The 1992 DM effort was performed at Giddings & Lewis (G&L) Measurement Systems in Dayton, Ohio. G&L manufactures an extensive line of measurement devices, including coordinate measuring machines. A coordinate measuring machine (CMM) was used to perform the data acquisition on the panels and molds. Postprocessing of the data and data reduction were done on a Silicon Graphics engineering workstation using PATRAN, a computer aided engineering (CAE) software package marketed by PDA Engineering, Inc. Additionally, some data reduction was done on personal computers using the Microsoft EXCEL spreadsheet program.

3.2.1 CMM Description

A CMM (Figure 14) is a programmable measurement device that incorporates a probe mobile in 3 directions with a spherical ruby tip, electronics for probe positioning, and part measuring routines to contact surface points on a part. The CMM monitors the probe X, Y, and Z position in the measurement space and records the coordinates of the probe position when contact is made with the measured item. Several advantages in using a CMM to measure items are accuracy, repeatability, automation, and minimal operator interface in data acquisition.

The Engineering Services Group at Giddings & Lewis has various CMMs available at different times to perform work for customers. For this effort several "ring-bridge" type CMMs were used. Figure 14 shows a CMM of this type, a CORDAX RS-30, on which all conical panels were dimensionally mapped. A larger CMM, an RS-50, was used for both the flat molds and the conical mold, and an even larger CMM, an RL-150, was used for the flat panels.

The details of the specifications for a CMM are quite complex, involving considerations for specifications relative to gauge surfaces, unknown surfaces, and flat or curved

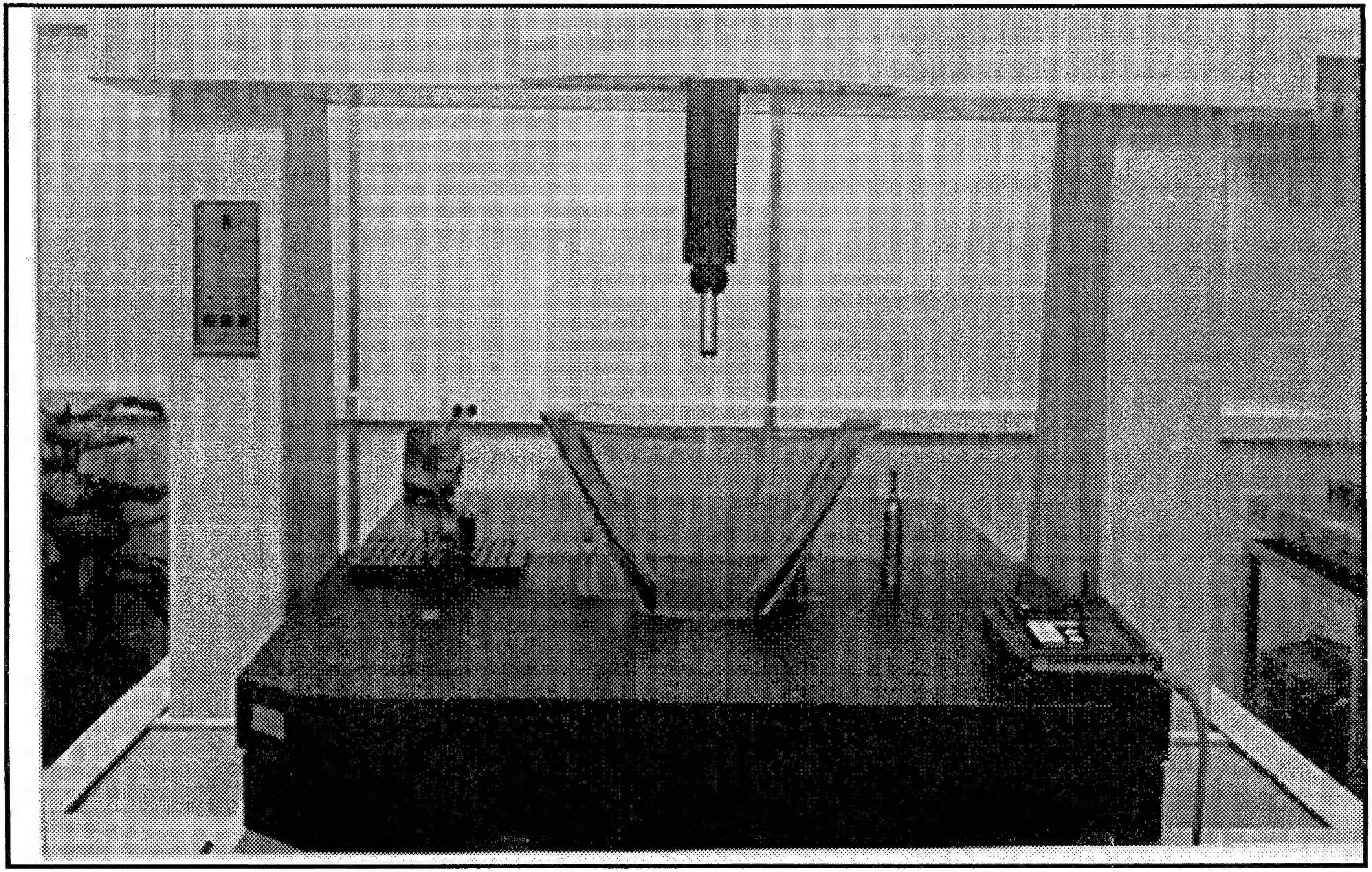


Figure 14. Ring-Bridge Coordinate Measuring Machine

surfaces. Table 8 lists a summary of the specifications of the CMMs as used on the different panels and molds.

Table 8. CMM Specification Summary

CMM Used		RS-30	RS-50	RS-50	RS-150
Items Mapped		Conical Panels	Cone Mold	Flat Panel Mold	Flat Panels
Linear Accuracy	X	0.00020"	0.00016"	0.00012"	0.00019"
	Y	0.00017"	0.00014"	0.00014"	0.00026"
	Z	0.00015"	0.00012"	0.00016"	0.00018"
Volumetric Accuracy		0.00043"	0.00040"	0.00040"	0.00045"
Repeatability		0.00016"	0.00016"	0.00016"	0.00016"

Linear accuracy is defined (by the U.S. Bureau of Weights and Measures) as the difference between the maximum and minimum measurements of an artifact measured many times in the particular coordinate direction. The linear accuracy value is sometimes viewed as twice the measurement accuracy of the CMM in the coordinate direction. For example, the Y-distance between two points on a RS-30 would have a measurement accuracy of ±0.000085 inch (85 millionths of an inch).

Volumetric accuracy is defined as the difference between the maximum and minimum measurements of an artifact measured many times in many orientations in the measurement volume of the CMM. The volumetric accuracy is sometimes viewed as twice the measurement accuracy of the CMM in the three combined directions. For example, the distance between two arbitrarily placed points in the measurement space of the RS-30 would have a measurement accuracy of ±0.000215 inch.

The repeatability of a CMM is a measure of how accurately the CMM can position its probe back in the same location after moving away from that location. To record the repeatability of the CMM as used on the plates and cones, a test procedure was run where the

probe contacted a series of 24 widely spaced points on the surfaces of a flat panel. The procedure was repeated 20 times. The standard deviation was calculated for the X, Y, and Z coordinates of the 24 points for all 20 cycles. The maximum standard deviation in X was 0.000119 inch, in Y was 0.000000 inch, and in Z was 0.000036 inch.

The linear accuracy, volumetric accuracy, and repeatability of the CMMs were used to establish measurement accuracies for the panels and molds. Table 9 summarizes these as measurement accuracies (i.e., a panel or mold measurement will have a measurement accuracy of ± the value shown in this table).

Table 9. Dimensional Mapping Measurement Tolerances (inches).

Part	Length	Width	Thickness	Overall Shrinkage	Thickness Shrinkage
Cones	0.00009	0.00010	0.000215	0.00016	0.00042
Plates	0.00013	0.00009	0.000225	0.00020	0.00043
Cone Mold	0.00007	0.00008	0.00020	N/A	N/A
Plate Molds	0.00007	0.00008	0.00020	N/A	N/A

3.2.2 Dimensional Mapping Procedure

Data acquisition by CMM can be highly automated. For the subject effort a part measurement program was developed by a Giddings & Lewis Applications Engineer for each type of panel, and the program was run to acquire the coordinates of the points of interest. This approach allowed the CMM to obtain data on each panel in the same fashion with no operator intervention after initial panel setup.

On the flat panels thickness values at target point locations described by a 1-inch by 1-inch grid on the 2-foot by 2-foot surfaces (Figure 15) were required. Also, the length and width of the flat panels were required at several locations. The same grid was used for the target

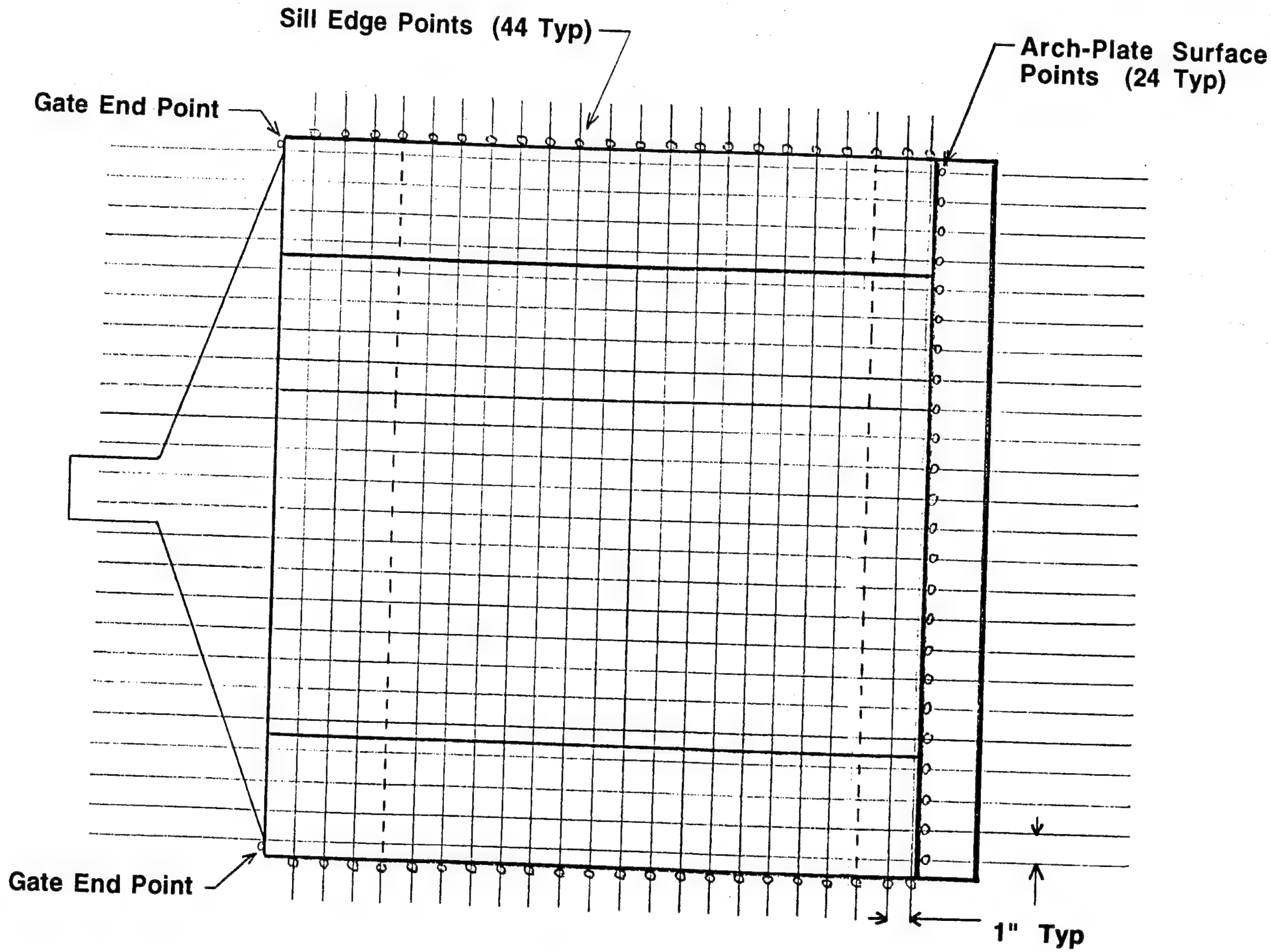


Figure 15. Flat Panel Grid Layout.

points on the flat panel mold. On the conical panels thickness values were required at target point locations described by a 1-inch by 5 degree grid on the optical surfaces of the panel and a 1-inch by 1-inch grid on the curved thickened sill surfaces (Figure 16). Again, the same grid of target point locations was used for the cone mold.

The task of the CMM operator was to locate these target points and to obtain the actual point coordinates in the same manner for each panel and its mold. It was essential that the same point location was contacted on each part. In only this way could comparisons between panels and between panels and molds be made. The procedure of staging (mounting) a part, locating the part in the measurement volume of the CMM, locating the target points, and approaching and contacting the points on the part is described in this section.

The electronics and software routines resident on the CMM eliminated the need to mount the parts precisely. The CMM can orient a frame of reference relative to a part instead of having the part fixtured precisely in a certain location and orientation relative to the CMM default frame of reference. Thus, the chance for error in fixturing was not present in the dimensional mapping of the panels and molds. Because the surfaces of the mold to be dimensionally mapped create an internal space enclosed by the two mold halves, there was no choice but to map the mold halves separately. This presented a challenge in bringing the two sets of data together in an accurate manner (one set for the mold core, one set for the mold cavity). The trials and errors of this are discussed in Section 3.2.3. In contrast to the molds, however, the panels were staged in such a manner that all target point coordinates could be obtained in one staging. This eliminated the need for bringing two sets of panel data together; all data acquired on the panels were relative to a single frame of reference.

3.2.2.1 Flat Panel Mapping

3.2.2.1.a Setup. The flat panels were staged on the CMM as shown in Figure 17. The panel was set upright on the starboard (lower) thickened sill surface. Blocks were placed under this surface so the target points on the surface could be contacted. The panel was held in place by a simple C-clamp and angle-iron jig. Although the flat panel data

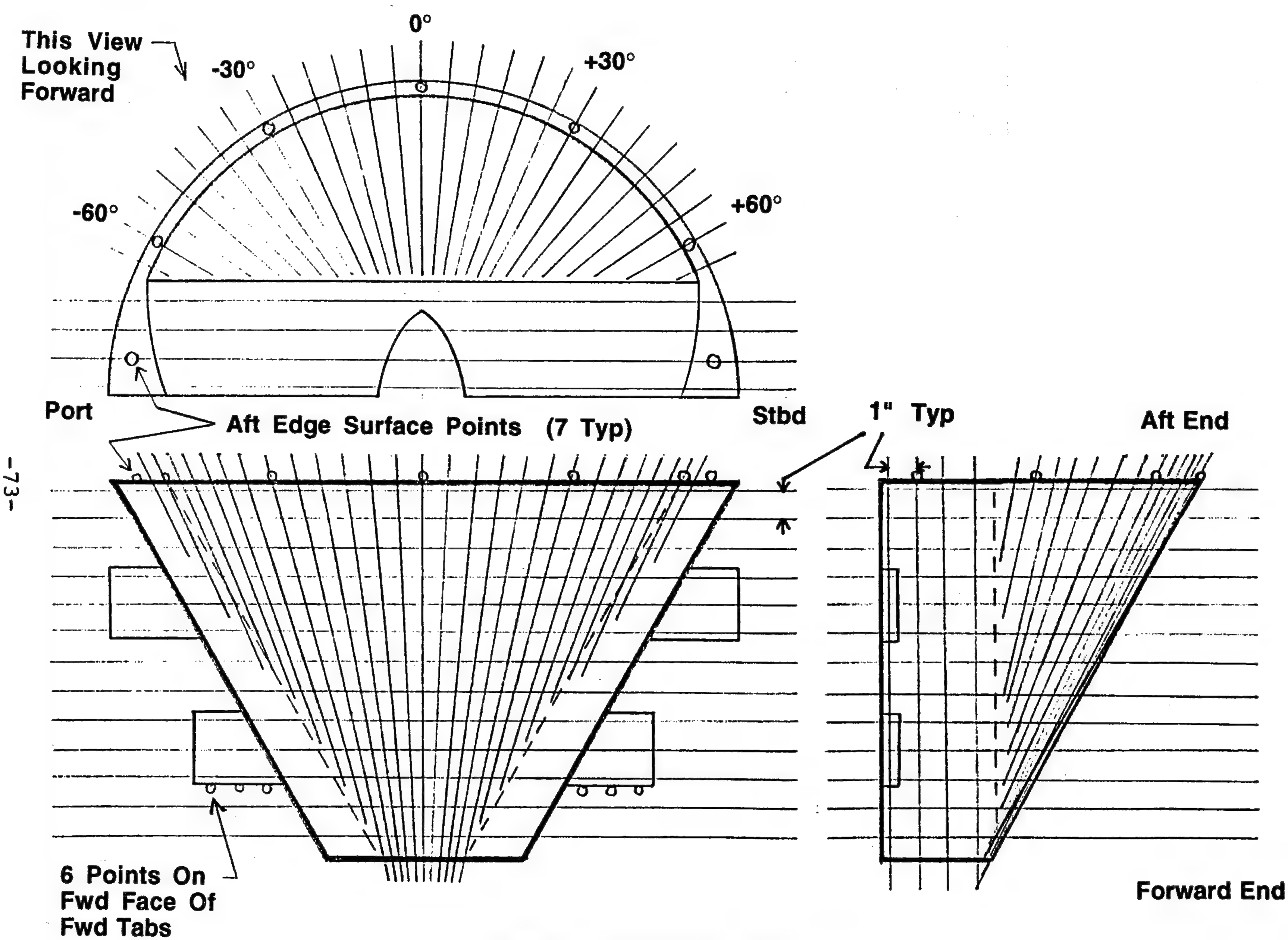


Figure 16. Conical Panel Grid Layout

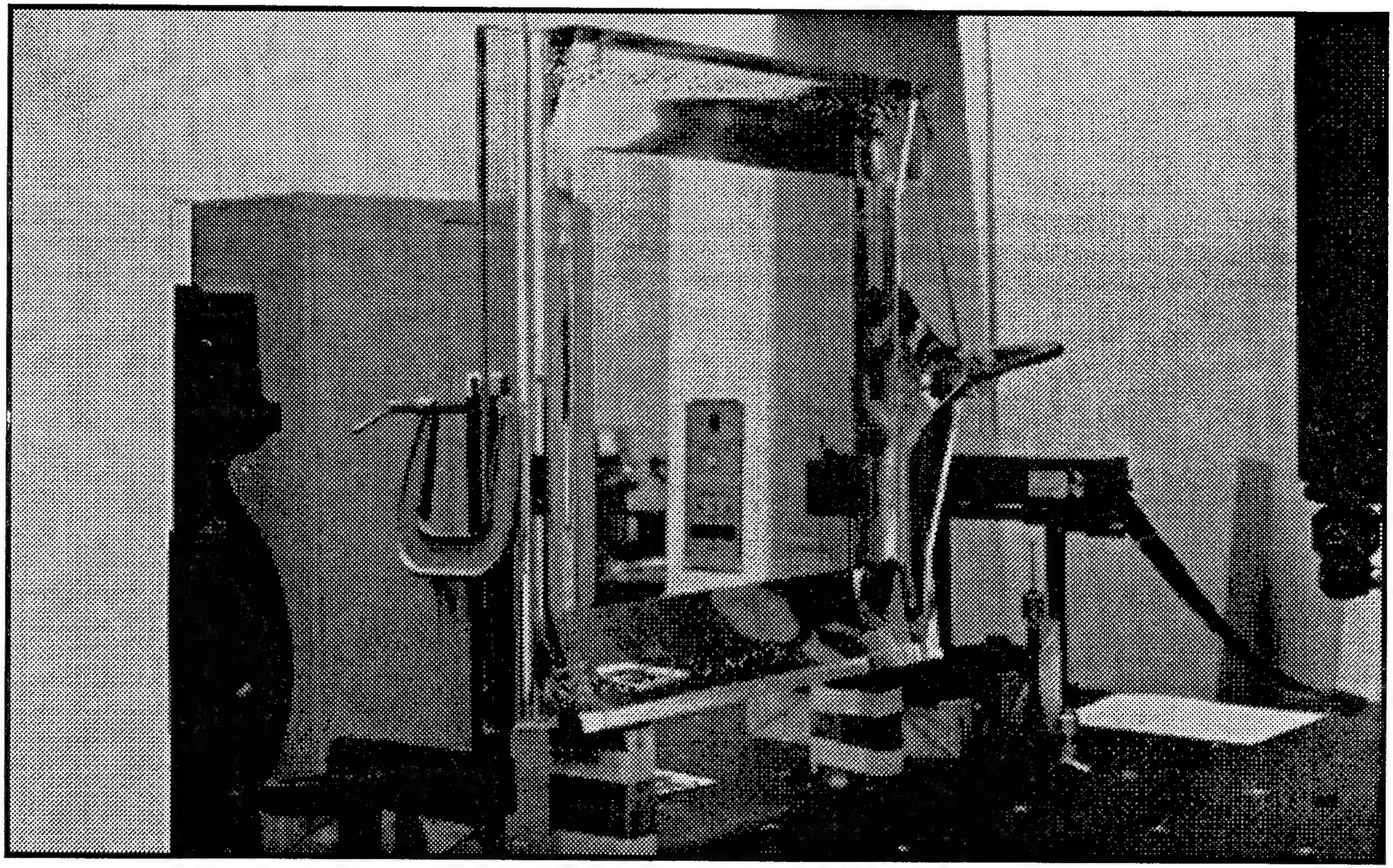


Figure 17. Flat Panel Staging.

acquisition program would automatically establish the reference frame and acquire the data, the operator had to initialize the program by supplying initial data to nominally locate the panel. This was accomplished by the operator manipulating the probe to contact several points on the panel. The operator touched three points on one of the optical surfaces, two points on the port (upper) thickened sill surface, and one point on the flat surface adjacent to the curved "arch" of the flat panel. The part program written for the flat panel contained the nominal dimensions of the panel, so with these operator-supplied points as initial input, the acquisition program could control the remainder of the mapping procedure.

3.2.2.1.b Reference Frame Establishment. Driven by the part program, the CMM first established a primary plane by touching seven widely spaced points on the core side optical surface (Figure 18). A best-fit plane was then calculated through the seven points and was defined as the X = 0 plane. Next, five points were touched on the arch-plate surface at X = -0.25 inch. A best-fit line was calculated through the five points, translated to X = 0, and defined as the Z axis. This fixed the X = 0 plane in rotation and defined the Y = 0 location on the X = 0 plane. The Z = 0 point on the Z axis was found by calculating the midline (panel centerline) between two lines best-fit through five points on each of the port and starboard thickened sill surfaces at X = 0. *(By definition, the midline and the panel centerline both lie in the plane of symmetry of the flat panel)*. This procedure produced a flat panel reference frame that had its origin on the panel centerline at the intersection of the core side optical surface and the arch-plate surface. This procedure for reference frame establishment was used on all flat panels, and a slightly modified procedure was used on the flat panel mold.

3.2.2.1.c Data Acquisition. With the reference frame established, the CMM proceeded to acquire the coordinates of the target points. During data acquisition the part program directed the probe to move in a systematic order across the panel optical surfaces. With the probe positioned approximately 1/4 inch off (in either the + or - X direction) of the intended surface, the CMM moved and positioned the probe to the desired Y and Z coordinates. Once in position, the probe then approached the surface in the desired X direction until contact was made. Upon contact the CMM first recorded the actual X, Y, Z coordinates of the probe tip center. Because the location of the target points for the flat panel were all on flat surfaces (see

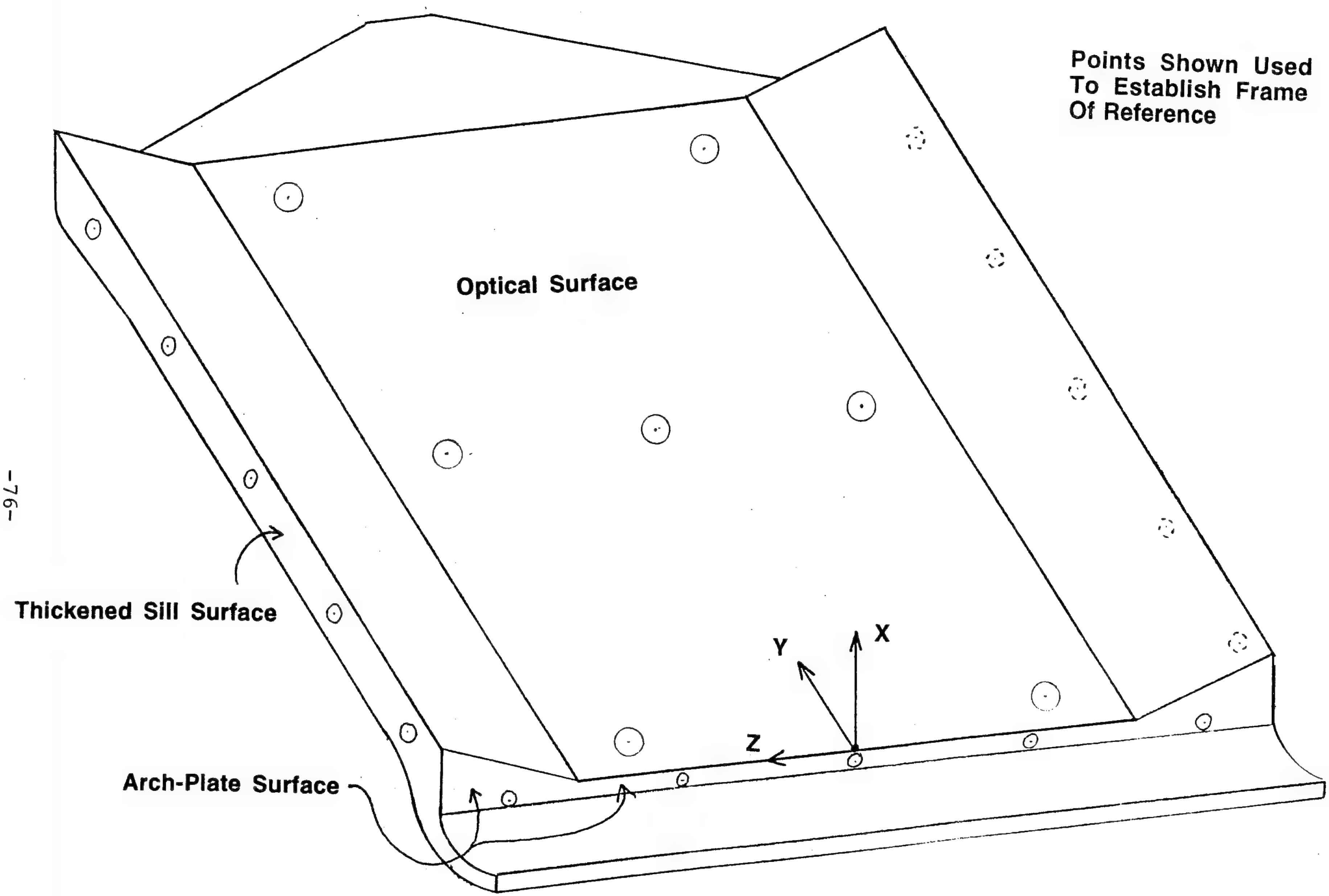


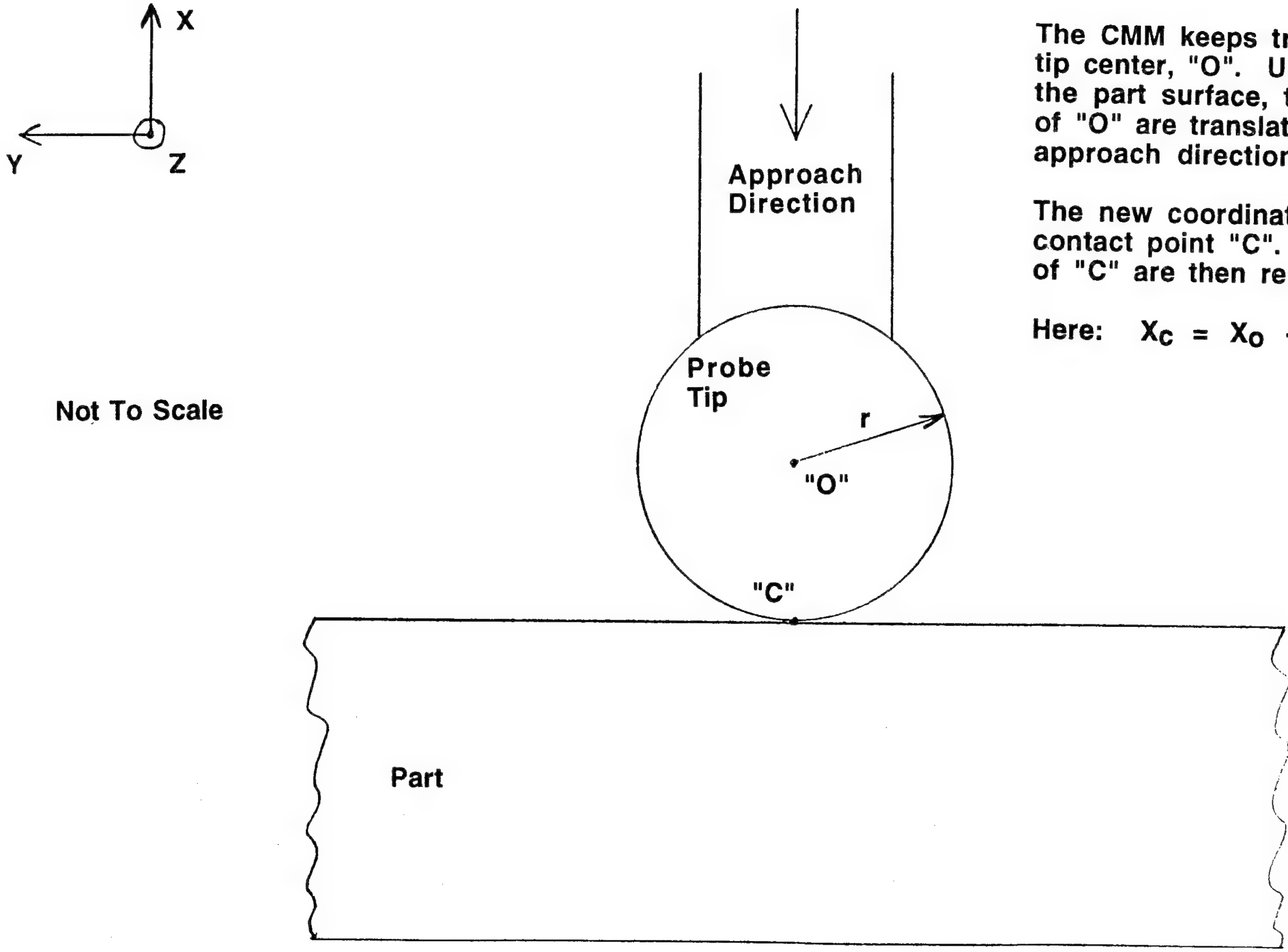
Figure 18. Flat Panel Reference System

exception in next paragraph), the CMM could easily approach the points in a normal direction. This simple surface shape allowed for a simple "ball radius compensation" to be calculated (Figure 19) by the CMM which translated the X, Y, Z coordinates of the probe tip center in the approach direction to the surface of the probe tip. This resulted in the X, Y, Z of the actual contact point. In a like manner the CMM obtained the coordinates of all target points on all the intended surfaces of the flat panels.

The majority of flat panels exhibit some obvious sink (between 1/32 - 1/16 inch deep) on the thickened sill surfaces (usually more obvious on the core side). This sink creates a surface that is not flat, but rather one that has a very slight curvature. A consequence of this slight curvature is that the probe tip does not contact the surface in a normal direction. This is called "ball tangency error" and is discussed in detail in paragraph 3.2.3.2. To be completely rigorous, the ball tangency error should be compensated for on these flat panel surfaces. However, because the magnitude of the error (less than 0.00005 inch) is smaller than the measurement accuracy, the compensation was not performed for the flat panels.

3.2.2.2 Flat Panel Mold Mapping

3.2.2.2.a <u>Reference Frame Establishment</u>. Because the surfaces of the mold to be dimensionally mapped create an internal space enclosed by the two mold halves, the mold halves were mapped separately. Although the mold surfaces are mirror images of the part surfaces, some features found on the cavity half of the mold are not present on the core half. For this reason reference frame establishment on the flat panel mold halves was modified from that of the flat panels. The core of the mold has all the surfaces required to establish the frame of reference in the same manner as the panel, using the optical surface, arch-plate surface, and thickened sill surfaces. The cavity, on the other hand, has no arch-plate surface. It only has a few very small surfaces at the thickened sill surfaces. The cavity does have an optical surface, although it is offset from the core side optical surface by either 1/2 or 3/4 inch (depending on which panel thickness is desired). To establish the "same" frame of reference on the cavity half, other features on the mold were used.



The CMM keeps track of the probe tip center, "O". Upon contact with the part surface, the coordinates of "O" are translated in the approach direction a distance r.

The new coordinates are those of contact point "C". The coordinates of "C" are then recorded.

Here: $X_C = X_O - r$

Figure 19. Ball Radius Compensation

During the molding operation the mold halves are aligned by conical guide pins on one half and conical sockets on the other half (Figure 20). The axes of the conical pins and sockets coincide when the mold is closed (i.e., each conical pin fits inside its respective conical socket). This property of coincident axes was used to assist in locating the "same" reference frame on the cavity half as on the core half.

When establishing the frame of reference on the core half, the intersections of the axes of the guide pin sockets with the parting plane were found. The positions of these intersection points were then recorded relative to the established frame of reference. In this manner the distances from the panel centerline and from the arch-plate surface to the intersection points were found. On the cavity half the primary plane and centerline were found using the cavity optical surface and the small thickened sill surfaces, respectively. A temporary arch-plate location was assumed in order to establish a temporary frame of reference. The intersection points of the guide pin axes with the parting plane were then found. Based on these intersection point locations, the temporary arch-plate surface was translated until the distance from the surface to the intersection points was the same distance as on the core half of the mold.

The procedure described in the above two paragraphs is for reference frame establishment; it does not describe the procedure for bringing core data together with cavity data. During the 1991 DM effort it was determined that the process of establishing the "same" frame of reference on two separate mold halves would not bring the reference frames into exact alignment. In order to have more confidence in bringing the data for the core together with the data for the cavity, 12 additional target points (6 on the core, 6 on the cavity) were identified for the mold. Six widely spaced parting plane points on the core were acquired, as were six similarly located parting plane points on the cavity. When the data halves were brought together, the two sets of six points should have been coincident. In practice this did not happen. Although the 1991 DM data were usable, lessons learned during that effort resulted in external tooling spheres being used in mold mapping in the 1992 effort. The reasons why and the adjustments made are discussed in paragraph 3.2.3.4.

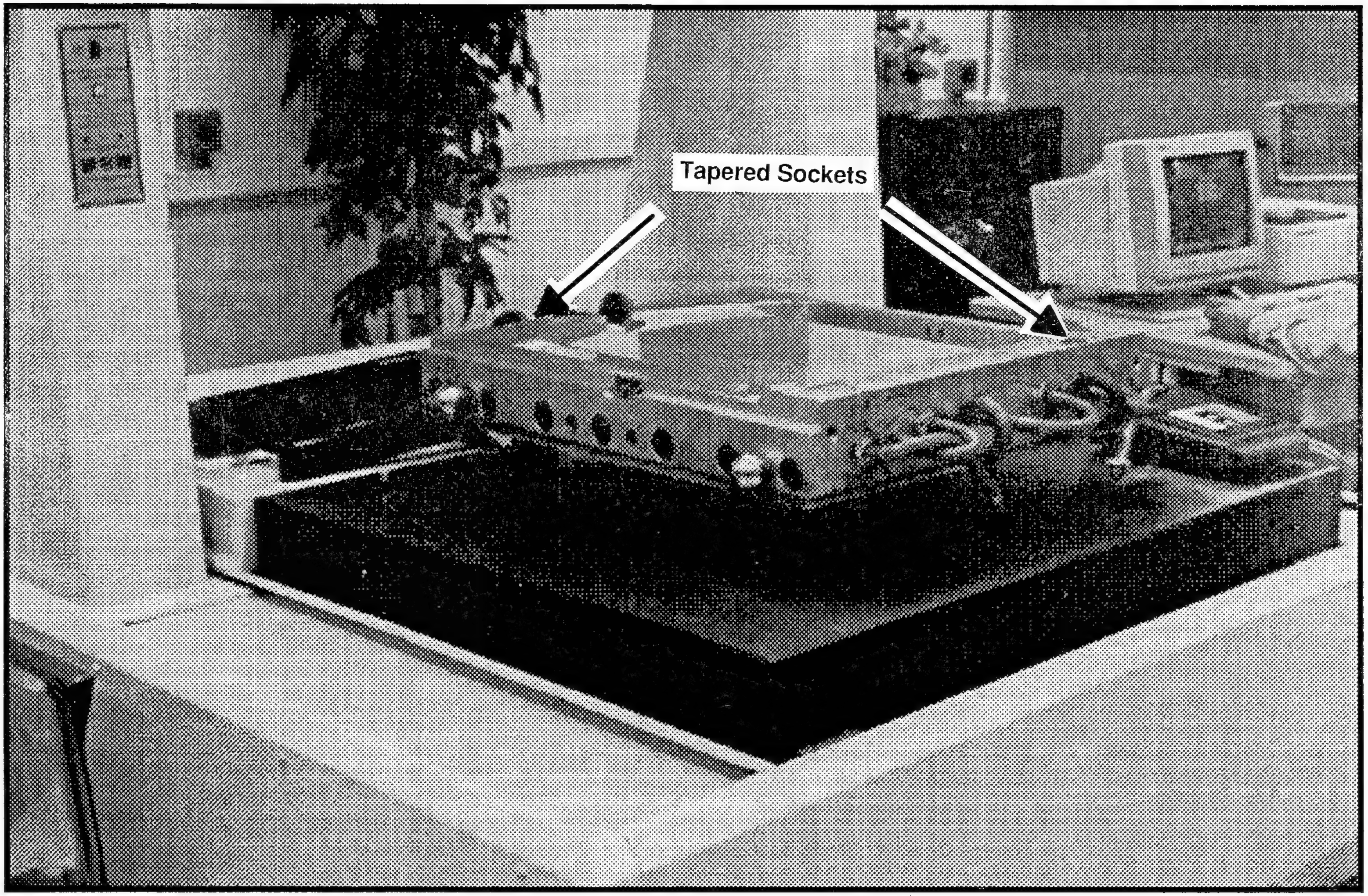


Figure 20. Flat Plate Mold - Tapered Sockets On Parting Plane

3.2.2.2.b Data Acquisition. After reference frame establishment, the dimensional mapping of the flat panel mold halves proceeded much in the same manner as on the panels. The probe was positioned over a target point in Y and Z and then approached in the X direction until contact was made. The same ball radius compensation was performed, and the contact point coordinates were recorded.

3.2.2.3 Conical Panel Mapping

3.2.2.3.a Setup. The conical panels were staged on the CMM as shown in Figure 21. The cone was placed nose down on the CMM table so that all desired target points were accessible by the probe. The cone was held in place with a simple clamping arrangement that applied a slight pressure to the aft faces of the two aft tabs (Figure 21 actually shows the clamps on the forward tabs). As with the flat panels, the CMM operator needed to manipulate the probe to contact several points on the cone so the CMM could locate the cone in its measuring volume. The operator touched three points on the flat semicircular aft edge surface, two points on each of the flat thickened sill surfaces, and three points on the outer optical surface. The part program written for the conical panels contained the nominal dimensions of the cone. With these operator-supplied points as initial input, the part program could control the mapping procedure.

3.2.2.3.b Reference Frame Establishment. The CMM first established a primary plane by touching seven widely spaced points on the flat semicircular aft edge surface (Figure 22). A best-fit plane was then calculated through the seven points, and this was defined as the $Y = 0$ plane. Next, three points were touched on each of the flat thickened sill surfaces. A best-fit plane was calculated through the six points, and the intersection of this plane with the primary $Y = 0$ plane was defined as the X axis. This fixed the $Y = 0$ plane in rotation and defined the $Z = 0$ location on the $Y = 0$ plane. Next, the probe touched seven equally spaced points on the outer optical surface at $Y = -0.25$ inch. A best fit circle was generated through the seven points, and the center point of the circle calculated and translated to the X axis. This procedure produced a conical panel reference frame that had its origin at the intersection of the aft edge surface plane and the axis of the conical outer surface. This procedure for reference

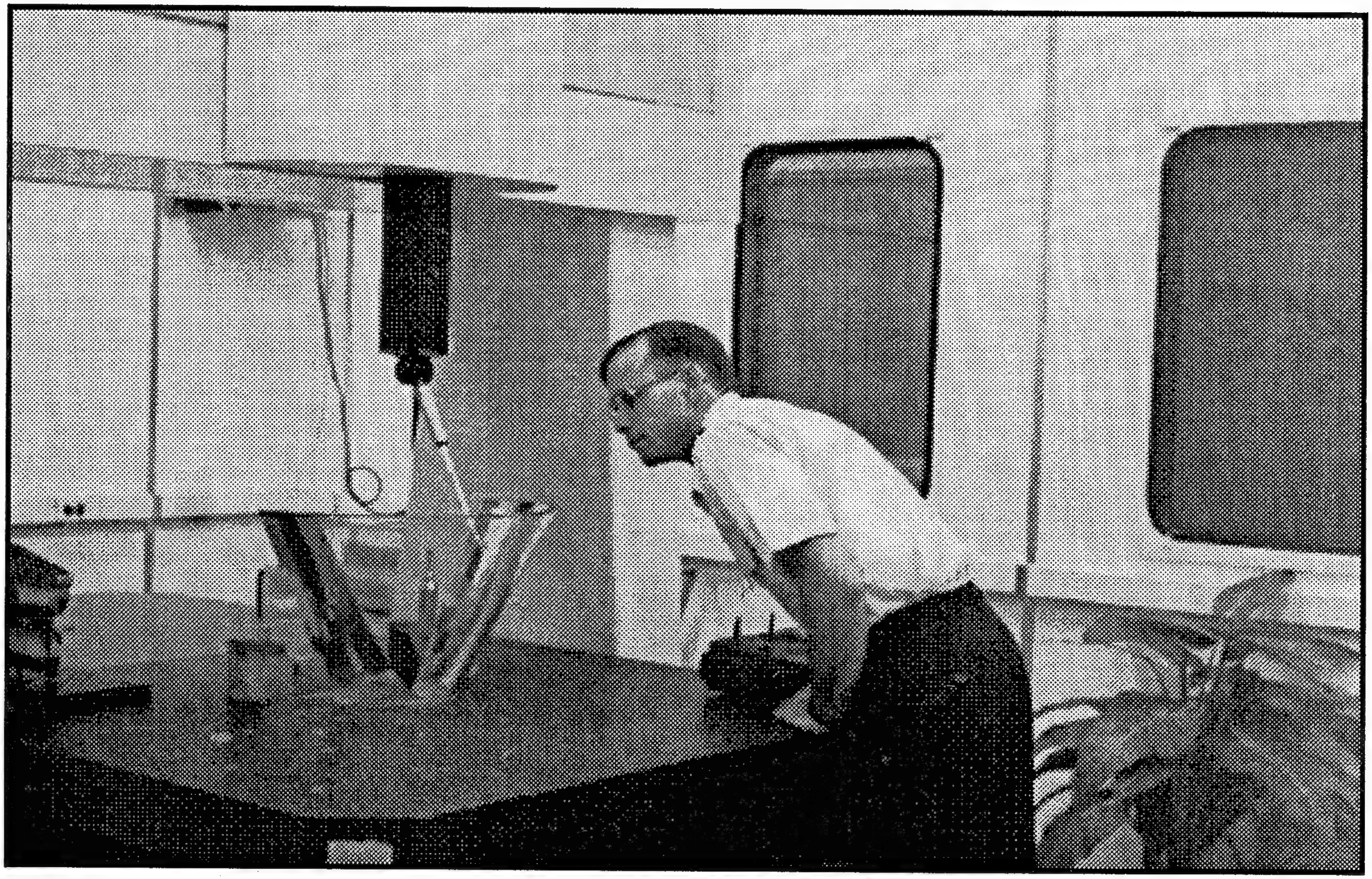


Figure 21. Conical Panel Staging

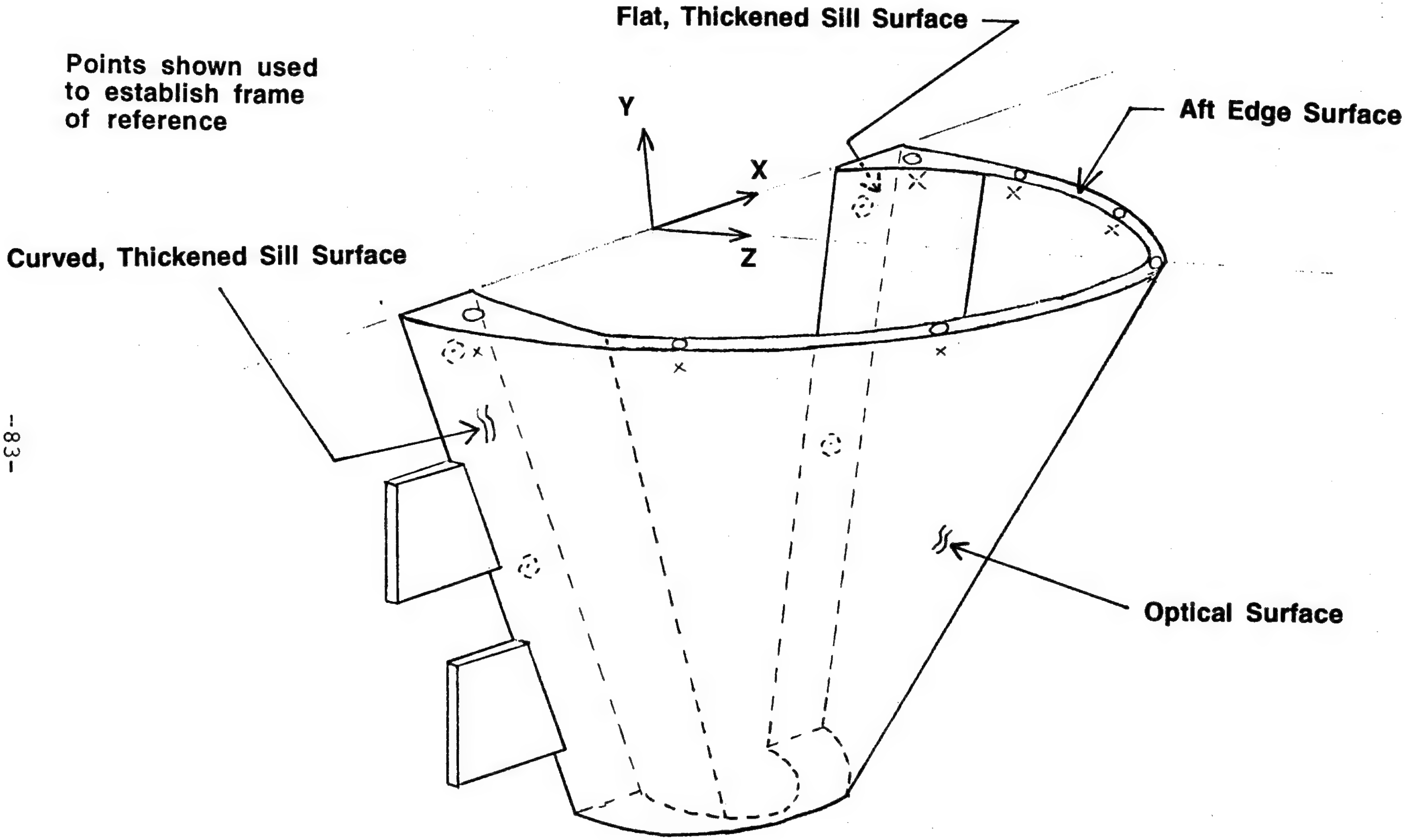


Figure 22. Conical Panel Reference System

frame establishment was used on all conical panels, and a slightly modified procedure was used on the cone mold.

3.2.2.3.c Data Acquisition. With the reference frame established, the CMM proceeded to acquire the coordinates of the target points. During data acquisition the part program directed the probe to move in a systematic order around the cone surfaces. A short discussion of the target point grid for the cone is in order here.

Curved, Thickened Sill Surface Target Points: The thickened sill surface target points were arranged in a 1-inch by 1-inch grid (see Figure 16). The grid was defined by the intersections of two sets of section cuts. One set of sections was parallel to the aft edge surface spaced 1 inch apart starting at 0.25 inch forward of the aft edge surface. The other set of sections was parallel to the flat thickened sill surface spaced 1 inch apart starting at 0.75 inch from the surface. This grid defined 4 stations (or rows) of target points on each of the 4 curved thickened sill surfaces with each station having 13 points in the aft to forward direction.

Optical Surface Target Points: The optical surface target points were arranged in a 1-inch by 5 degree grid. The grid was defined by the intersections of two sets of section cuts. As on the sill surfaces, one set of sections was parallel to the aft edge surface, spaced 1 inch apart, starting at 0.25 inch forward of the aft edge. The other set consisted of radial sections originating on the cone axis. These included a centerline section and sections from +65 degrees from centerline to -65 degrees from centerline at 5 degree increments. This grid defined 27 stations of target points with a varying number of points in each station counting from aft to forward. The centerline station had 13 points, while the ± 65 degree stations only had 3 points each.

At the thickened sill surfaces the CMM acquired data by positioning the probe at the desired Y and Z coordinates. Once in position, the probe then approached the surface in the desired X direction (either inboard or outboard) until contact was made. At the optical surfaces the CMM positioned the probe at the desired Y coordinate and

then approached the surface along the radial direction toward (or away from) the cone axis. Upon contact the CMM first recorded the actual X, Y, Z coordinates of the probe tip center. As with the flat panels, the simple "ball radius compensation" (Figure 19) was calculated by the CMM which translated the X, Y, Z coordinates of the probe tip center to the surface of the probe tip in the approach direction. In a like manner the CMM obtained the coordinates of all target points on all the intended surfaces of the conical panels. However, unlike the flat panels where approach by the probe was normal to the surface, the actual contact on the cone surfaces was not completely normal to the approach direction. This effect is called "ball tangency error" and was compensated for during the reduction of the conical data. Ball tangency error is discussed in paragraph 3.2.3.2.

3.2.2.4 Conical Panel Mold Mapping

3.2.2.4.a Reference Frame Establishment. As with the flat panel mold, the cone mold halves had to be mapped separately. Also like the flat panel mold, the parting plane and tapered pins and sockets were used to align the two reference frames with each other. The core half of the cone mold had all features necessary to establish its reference frame in the same manner as the conical panel (Figure 23). Intersection points of the socket axes and the parting plane were also found. These intersections were used to assist in reference frame establishment on the cavity half. The features used on the cavity half were the conical surface, parting plane, and the tapered pin axes. Through translations of feature locations, the cavity and core mold half reference frames were brought into alignment.

As discussed in paragraph 3.2.2.2.a, 12 additional parting plane target points (6 on the core, 6 on the cavity) were identified for the cone mold to assist in bringing the 2 halves of data together during data reduction. However, as with the flat panel mold, external tooling spheres were later used in the 1992 DM effort to permit more accurate alignment of the data halves. The procedures and benefits of using tooling spheres are discussed in paragraph 3.2.3.4.

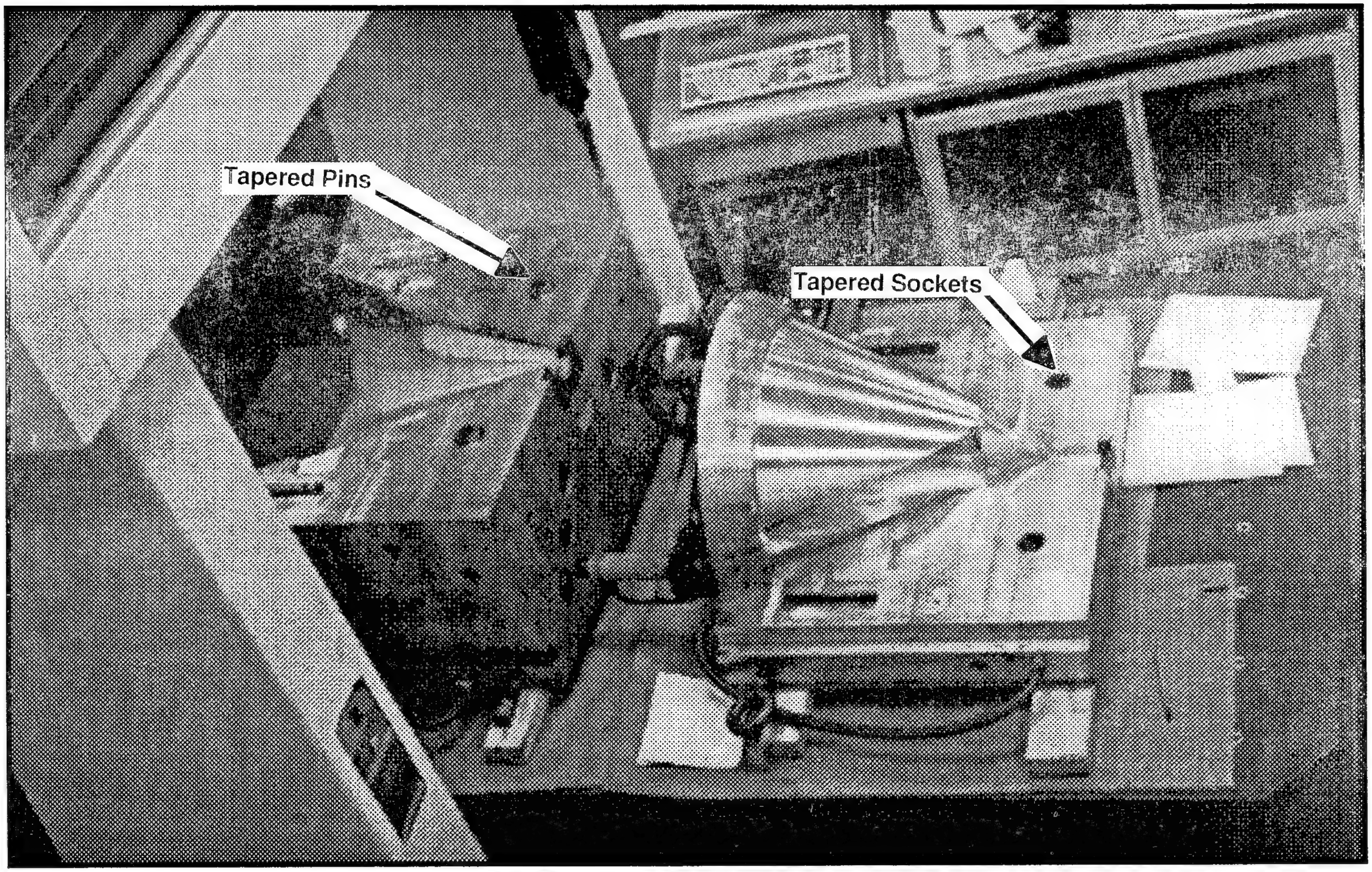


Figure 23. Cone Mold - Tapered Pins and Sockets

3.2.2.4.b Data Acquisition. After reference frame establishment, the dimensional mapping of the cone mold halves proceeded like the DM of the panels. At the thickened sill surfaces the probe was positioned over a target point in Y and Z and then approached in the X direction until contact was made. The ball radius compensation was performed, and the X, Y, Z coordinates were recorded.

For the optical surfaces the CMM positioned the probe at the desired Z coordinate and then approached the surface along the radial direction toward (or away from) the cone axis until contact was made. The ball radius compensation was performed, and the X, Y, Z coordinates were recorded. In a like manner the CMM obtained the coordinates of all target points on all the intended surfaces of the cone mold halves. The ball tangency error encountered was compensated for during data reduction.

3.2.3 Data Reduction and Post Processing

The data for each of the panels and mold halves were delivered as ASCII text files on computer diskette. The data were transferred to a workstation and converted to a format readable by PATRAN. Once read into PATRAN, the data were processed using 3D modeling and display capabilities, making the task of data reduction and postprocessing easier to visualize (Figures 24 to 26). The data reduction procedure consisted of correcting for ball tangency error on the conical panel and mold and calculating thickness values and overall dimensions from the point coordinates. Overall shrinkage values were calculated by obtaining the difference between mold overall dimensions and panel overall dimensions, and dividing the difference by the mold overall dimension [i.e., (Mold length - Panel length) / (Mold length)]. The panel thickness values were calculated in the same manner [i.e., (Mold thickness - Panel thickness) / (Mold thickness)]. The postprocessing consisted of creating contour plots (Figure 27) and X-Y plots of thickness and shrinkage results (Figure 28).

Appropriate care was taken to account for the reversed direction of approach to mold surfaces as compared to panel surfaces. When the probe approached the outer surface of the panel, it traveled toward the cone axis. The associated ball tangency error caused a recorded

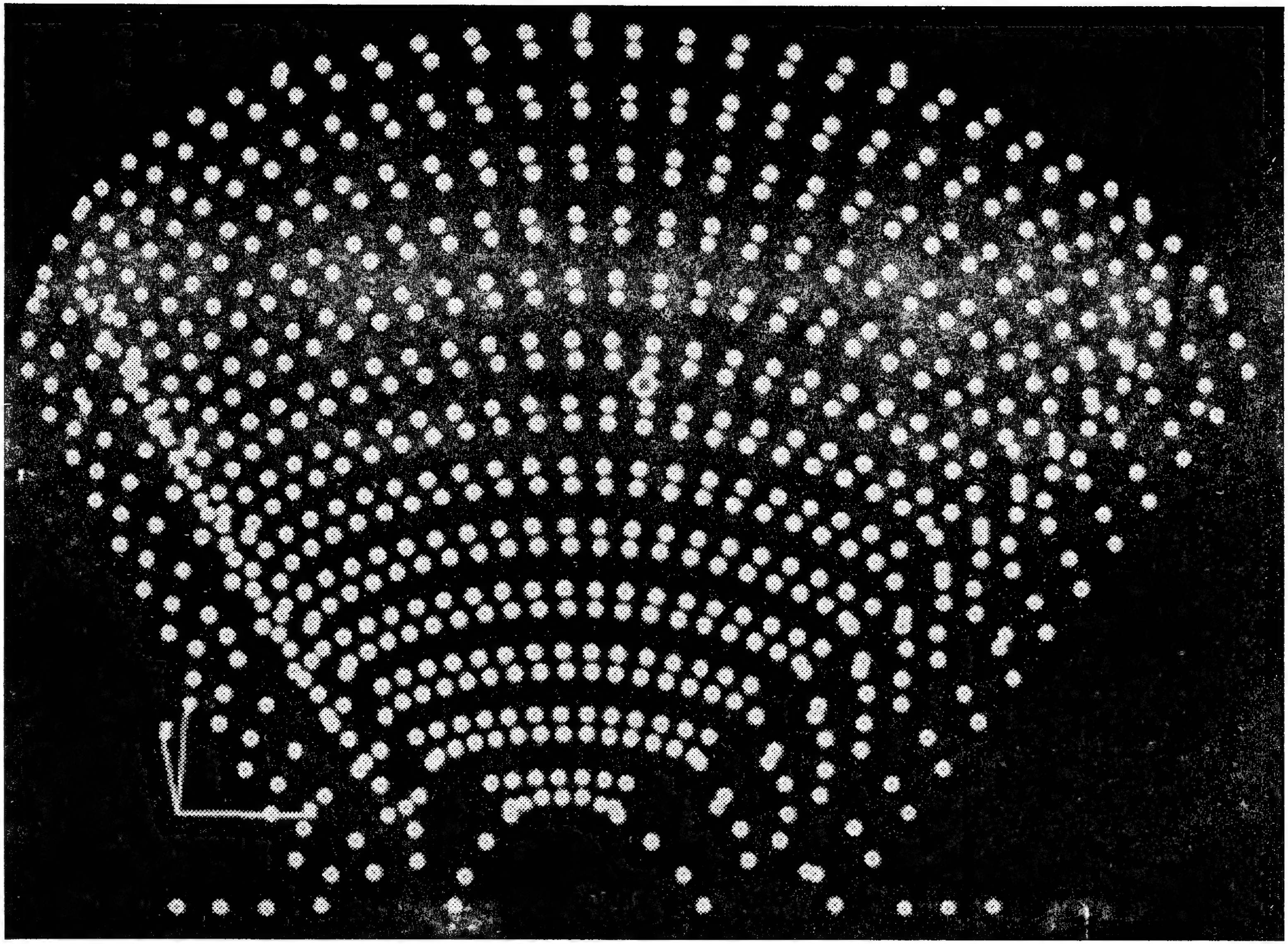


Figure 24. CMM Data Points Transferred To Workstation

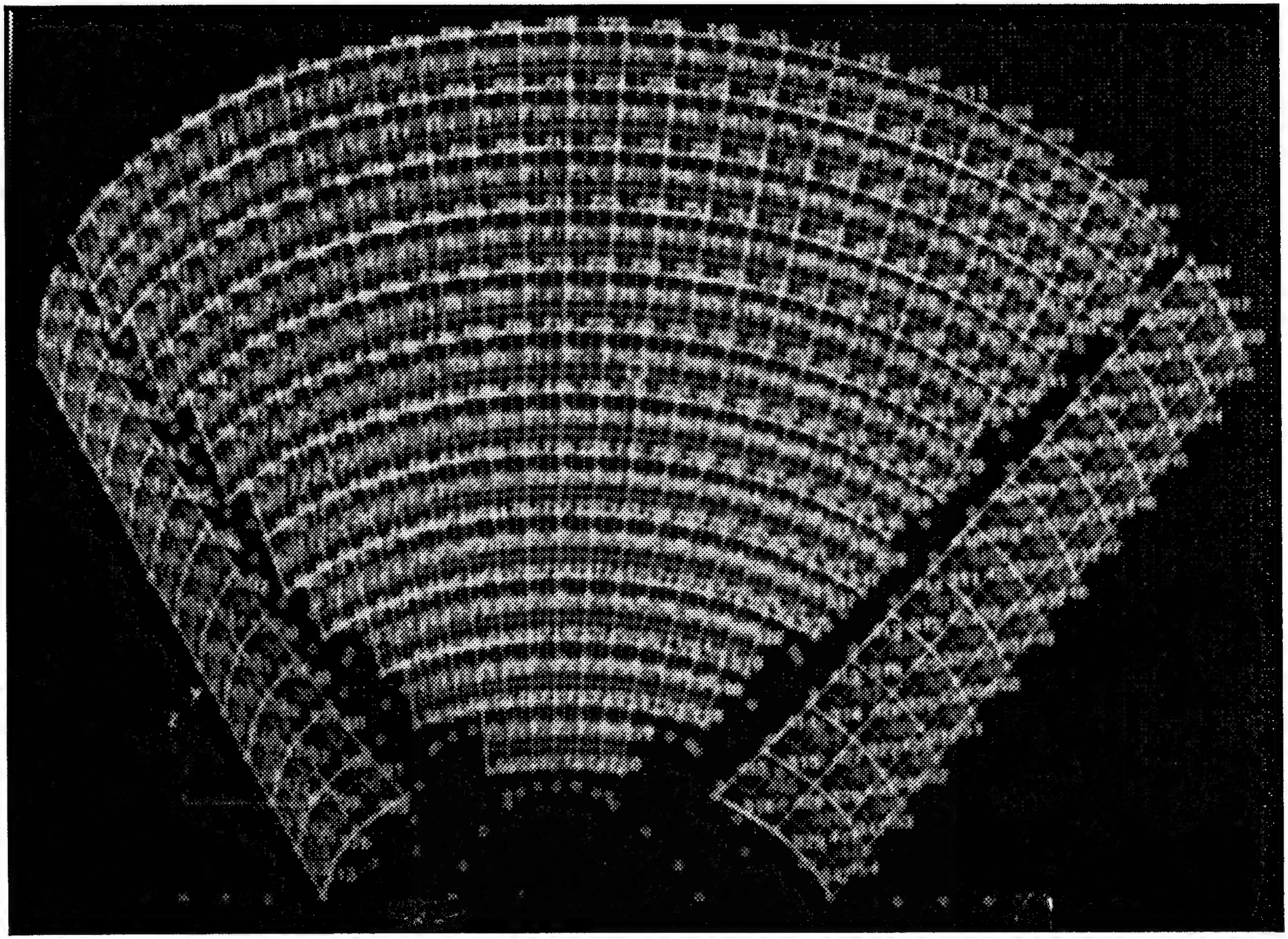


Figure 25. Surfaces Containing CMM Data Points

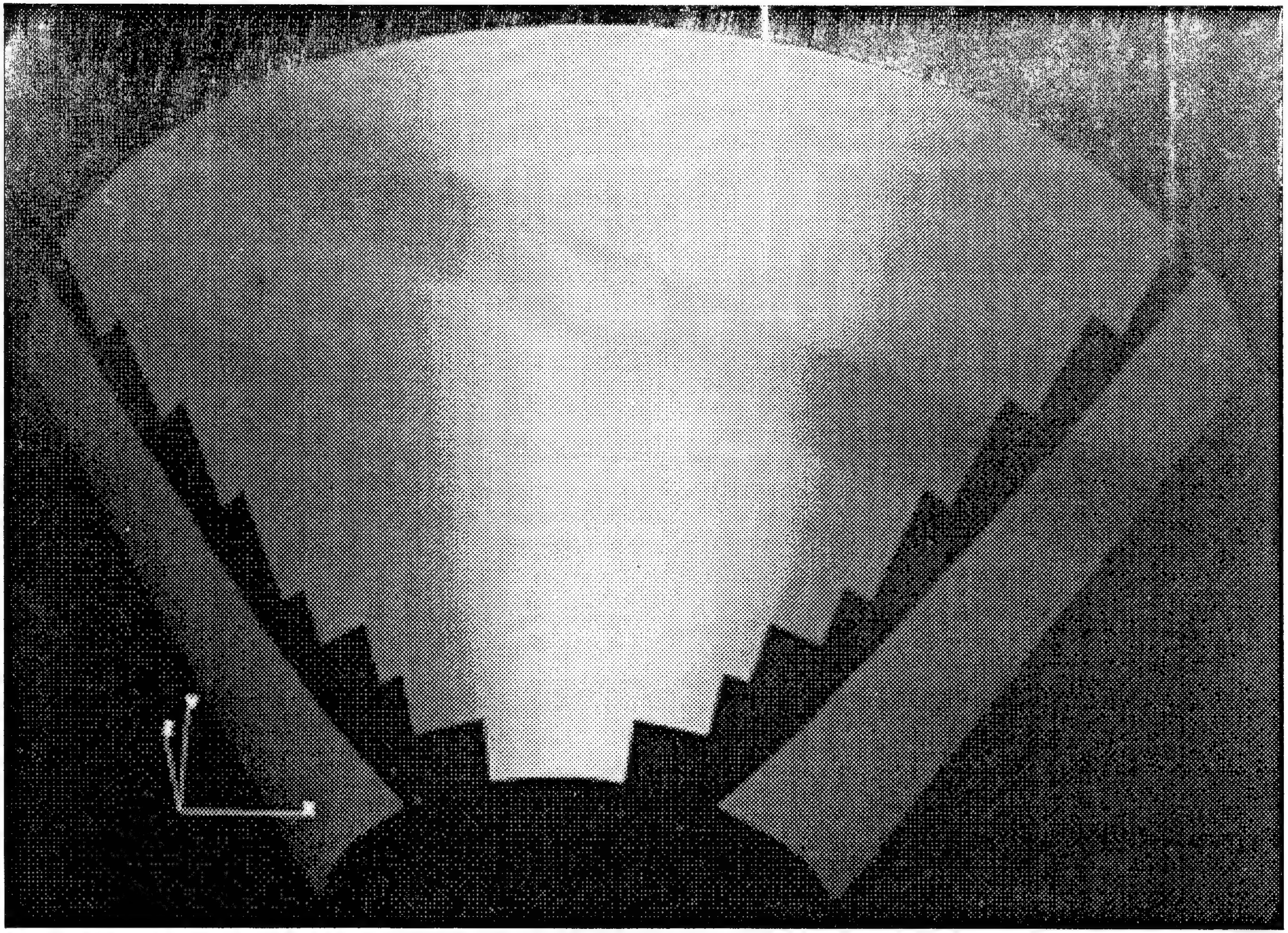


Figure 26. Solid Shading Of Surfaces Containing CMM Data Points

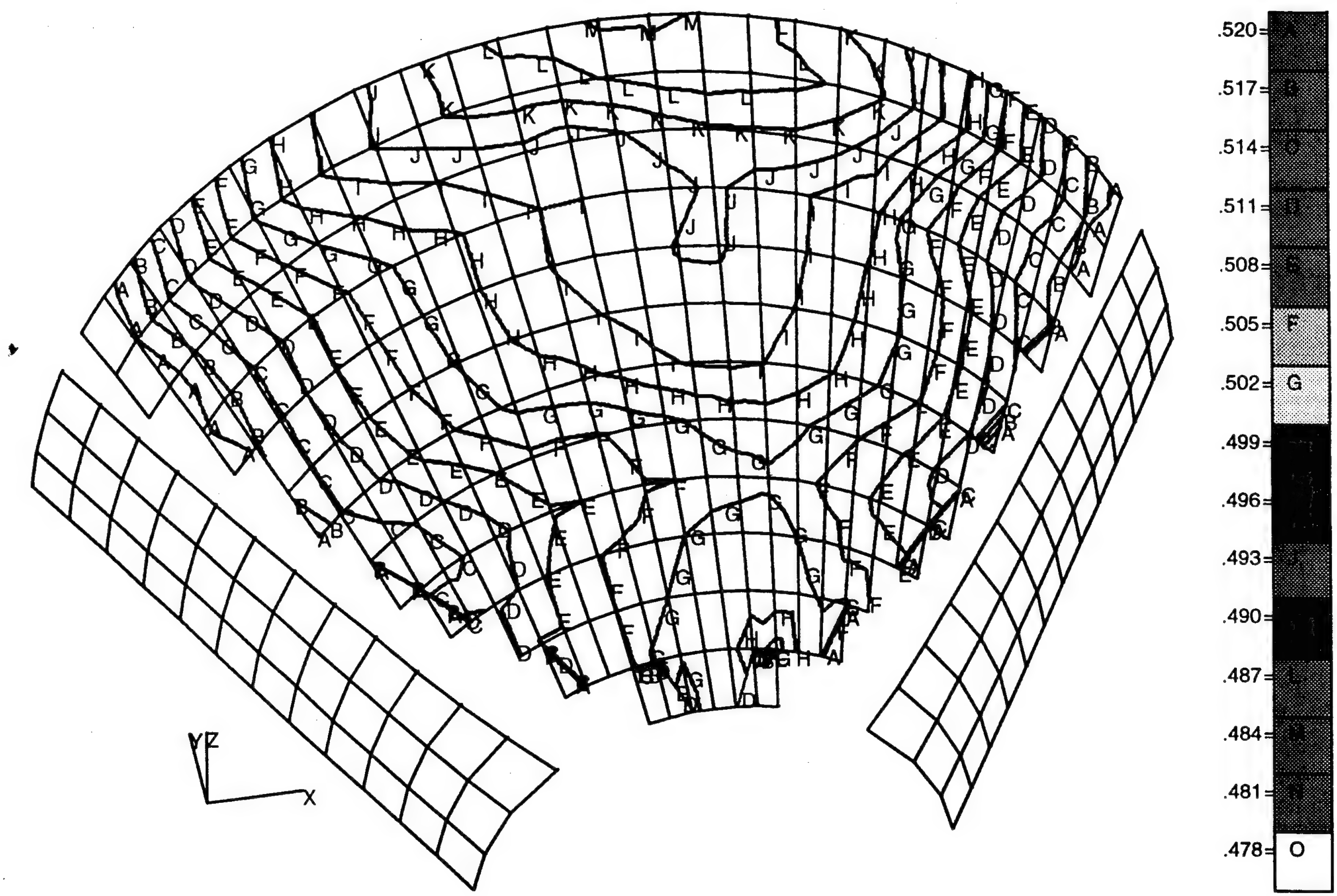


Figure 27. Contour Plot of Cone Thickness Values

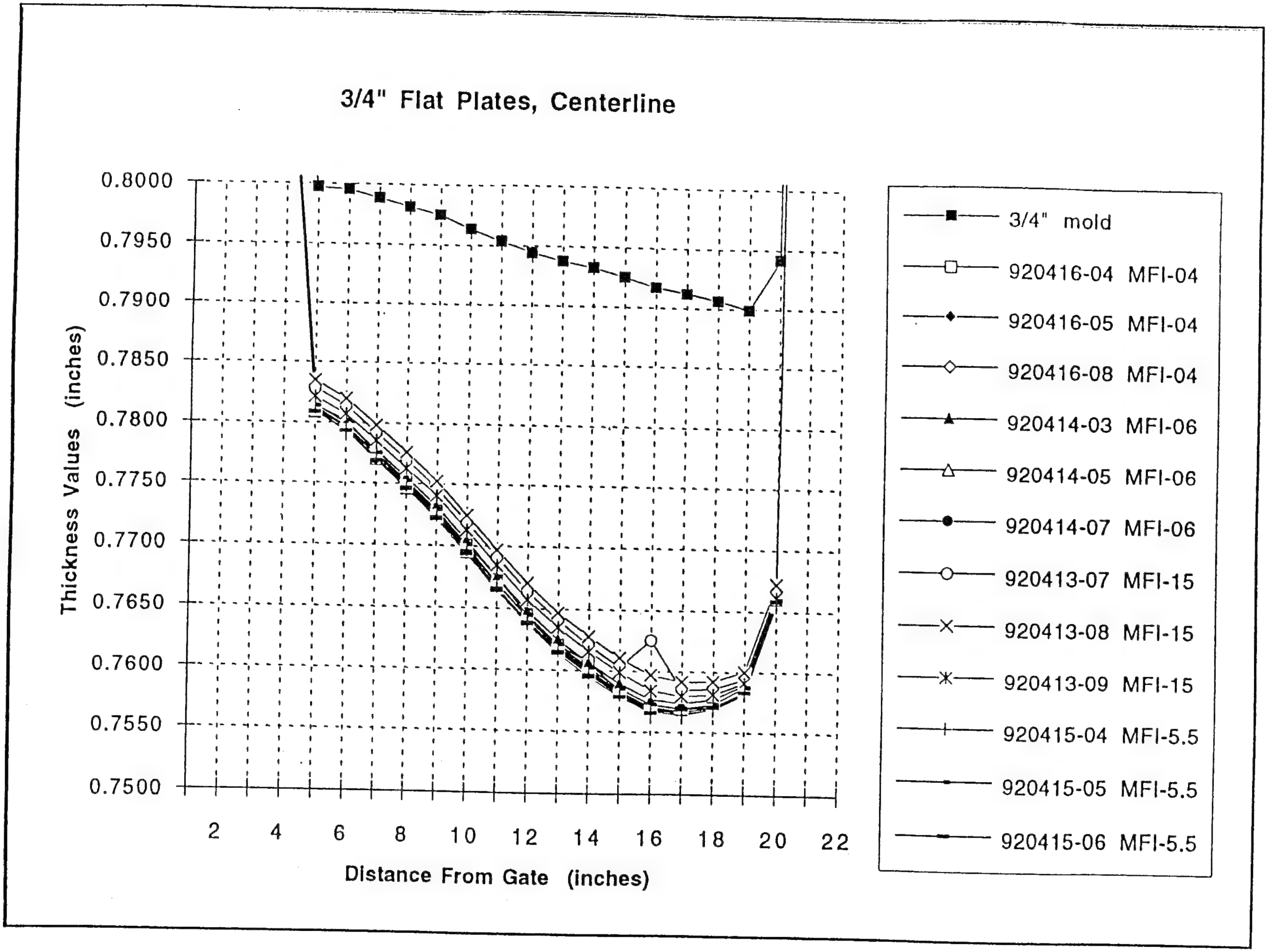


Figure 28. X-Y Plot of Flat Plate Thickness Data

point coordinate that had to be compensated by translating the point toward the cone axis along the approach direction. In contrast, when the probe approached the outer surface of the mold, it traveled away from the cone axis. The associated ball tangency error caused a recorded point coordinate that had to be compensated by translating the point away from the cone axis along the approach direction.

3.2.3.1 Flat Panels and Mold

Since the CMM probe had approached the flat panel and mold surfaces in a direction normal to the surface, the delivered data were coordinates of actual contact points. Furthermore, the grid of target points was constructed such that the points on the core side of the mold had the same Y and Z coordinates as the points on the cavity side (Figure 20). Thickness calculations were performed by finding the difference in X coordinates between corresponding core and cavity points. Typical thickness results for the flat panels are shown in Figure 28. The length measurements were determined by determining the difference in Y coordinates between corresponding points on the arch end of the panel and the gate end of the panel. Likewise, width measurements were determined by finding the difference in Z coordinates between corresponding points on opposite thickened sill surfaces. Table 10 shows the overall lengths and widths of the dimensionally mapped plates. Table 11 shows the calculated overall shrinkage values.

3.2.3.2 Conical Panels and Mold

The thickness and overall dimension calculations for the cones and the mold required additional calculations because of the ball tangency error noted in paragraph 3.2.2.3.c. Figure 29 is an enlarged representation of the probe tip contacting a conical panel optical surface. The probe approaches the target point T at a constant Z value, toward and normal to the cone axis. Instead of contacting point T, however, actual contact is made at point A. The CMM monitors the probe tip center O, and upon contact performs the ball radius compensation that results in the coordinates of point C being recorded. The point recorded is short from the target point T by the distance "d." If not corrected, the result would be panel data that showed thicknesses greater than actual and mold data that showed thicknesses less than

Table 10. Flat Panels, Overall Dimensions

(Measurement Tolerance = 0.0001", from DM specs)

Panel Description	Resin Description	Panel ID	Port Side Length Lp (In.)	Stbd Side Length Ls (in.)	Sill to Sill Width at Arch End SS1 (in.)	Sill to Sill Width In Middle SS2 (in.)	Sill to Sill Width at Gate End SS3 (in.)
3/4" Plate Mold			22.2069	22.2105	24.1670	24.1653	24.1666
3/4" Plate	Dow 300-4	920416-04	22.0585	22.0624	24.0033	24.0062	24.0109
3/4" Plate	Dow 300-4	920416-05	22.0590	22.0635	24.0097	24.0137	24.0193
3/4" Plate	Dow 300-4	920416-08	22.0591	22.0632	24.0110	24.0140	24.0211
3/4" Plate	Dow XU7-5.5	920415-04	22.0599	22.0644	24.0093	24.0149	24.0206
3/4" Plate	Dow XU7-5.5	920415-05	22.0644	22.0648	24.0114	24.0160	24.0233
3/4" Plate	Dow XU7-5.5	920415-06	22.0616	22.0646	24.0108	24.0143	24.0222
3/4" Plate	Dow 300-6	920414-03	22.0634	22.0678	24.0126	24.0173	24.0256
3/4" Plate	Dow 300-6	920414-05	22.0587	22.0631	24.0127	24.0170	24.0218
3/4" Plate	Dow 300-6	920414-07	22.0590	22.0641	24.0118	24.0173	24.0236
3/4" Plate	Dow 300-15	920413-07	22.0611	22.0651	24.0101	24.0137	24.0201
3/4" Plate	Dow 300-15	920413-08	22.0625	22.0676	24.0138	24.0191	24.0264
3/4" Plate	Dow 300-15	920413-09	22.0635	22.0672	24.0163	24.0198	24.0268
1/2" Plate Mold			22.2050	22.2081	24.1654	24.1658	24.1660
1/2" Plate	Dow 300-4	920415-04	22.0553	22.0574	24.0038	24.0119	24.0133
1/2" Plate	Dow 300-4	920415-05	22.0601	22.0614	24.0021	24.0119	24.0148
1/2" Plate	Dow 300-4	920415-07	22.0543	22.0563	24.0036	24.0119	24.0126
1/2" Plate	Dow XU7-5.5	920415-04	22.0532	22.0554	24.0054	24.0126	24.0139
1/2" Plate	Dow XU7-5.5	920415-05	22.0531	22.0554	24.0061	24.0130	24.0144
1/2" Plate	Dow XU7-5.5	920415-06	22.0529	22.0558	24.0060	24.0135	24.0141
1/2" Plate	Dow 300-6	920414-04	22.0554	22.0592	24.0032	24.0125	24.0137
1/2" Plate	Dow 300-6	920414-06	22.0567	22.0616	24.0057	24.0147	24.0154
1/2" Plate	Dow 300-6	920414-07	22.0524	22.0561	24.0068	24.0147	24.0145
1/2" Plate	Dow 300-15	920414-04	22.0552	22.0582	24.0039	24.0125	24.0146
1/2" Plate	Dow 300-15	920414-06	22.0570	22.0608	24.0060	24.0145	24.0160
1/2" Plate	Dow 300-15	920414-08	22.0561	22.0595	24.0069	24.0150	24.0165
		AVERAGE(All Plates)	22.0580	22.0615	24.0080	24.0143	24.0181
		STDEV(All Plates)	0.0035	0.0039	0.0039	0.0027	0.0047
		AVERAGE(Dow 300-4)	22.0577	22.0607	24.0056	24.0116	24.0153
		STDEV(Dow 300-4)	0.0023	0.0031	0.0038	0.0028	0.0040
		AVERAGE(Dow XU7-5.5)	22.0575	22.0601	24.0082	24.0141	24.0181
		STDEV(Dow XU7-5.5)	0.0051	0.0050	0.0027	0.0013	0.0044
		AVERAGE(Dow 300-6)	22.0576	22.0620	24.0088	24.0156	24.0191
		STDEV(Dow 300-6)	0.0037	0.0040	0.0041	0.0019	0.0052
		AVERAGE(Dow 300-15)	22.0592	22.0631	24.0095	24.0158	24.0201
		STDEV(Dow 300-15)	0.0035	0.0041	0.0048	0.0030	0.0054

Table 11. Flat Panels, Overall Shrinkage Values

(Shrinkage Tolerance = 0.0002 inch/inch, from DM specs)

SHRINKAGE = [Mold Dimension - Part Dimension] / [Mold Dimension]

Panel Description	Resin Description	Panel ID	Port Side Shrinkage (inch/inch)	Stbd Side Shrinkage (inch/inch)	Sill to Sill Shrinkage at Arch End (inch/inch)	Sill to Sill Shrinkage in Middle (inch/inch)	Sill to Sill Shrinkage at Gate End (inch/inch)
3/4" Plate	Dow 300-4	920416-04	0.0067	0.0067	0.0068	0.0066	0.0064
3/4" Plate	Dow 300-4	920416-05	0.0067	0.0066	0.0065	0.0063	0.0061
3/4" Plate	Dow 300-4	920416-08	0.0067	0.0066	0.0065	0.0063	0.0060
3/4" Plate	Dow XU7-5.5	920415-04	0.0066	0.0066	0.0065	0.0062	0.0060
3/4" Plate	Dow XU7-5.5	920415-05	0.0064	0.0066	0.0064	0.0062	0.0059
3/4" Plate	Dow XU7-5.5	920415-06	0.0065	0.0066	0.0065	0.0062	0.0060
3/4" Plate	Dow 300-6	920414-03	0.0065	0.0064	0.0064	0.0061	0.0058
3/4" Plate	Dow 300-6	920414-05	0.0067	0.0066	0.0064	0.0061	0.0060
3/4" Plate	Dow 300-6	920414-07	0.0067	0.0066	0.0064	0.0061	0.0059
3/4" Plate	Dow 300-15	920413-07	0.0066	0.0065	0.0065	0.0063	0.0061
3/4" Plate	Dow 300-15	920413-08	0.0065	0.0064	0.0063	0.0061	0.0058
3/4" Plate	Dow 300-15	920413-09	0.0065	0.0065	0.0062	0.0060	0.0058
1/2" Plate	Dow 300-4	920415-04	0.0067	0.0068	0.0067	0.0064	0.0063
1/2" Plate	Dow 300-4	920415-05	0.0065	0.0066	0.0068	0.0064	0.0063
1/2" Plate	Dow 300-4	920415-07	0.0068	0.0068	0.0067	0.0064	0.0063
1/2" Plate	Dow XU7-5.5	920415-04	0.0068	0.0069	0.0066	0.0063	0.0063
1/2" Plate	Dow XU7-5.5	920415-05	0.0068	0.0069	0.0066	0.0063	0.0063
1/2" Plate	Dow XU7-5.5	920415-06	0.0068	0.0069	0.0066	0.0063	0.0063
1/2" Plate	Dow 300-6	920414-04	0.0067	0.0067	0.0067	0.0063	0.0063
1/2" Plate	Dow 300-6	920414-06	0.0067	0.0066	0.0066	0.0063	0.0062
1/2" Plate	Dow 300-6	920414-07	0.0069	0.0068	0.0066	0.0063	0.0063
1/2" Plate	Dow 300-15	920414-04	0.0067	0.0067	0.0067	0.0063	0.0063
1/2" Plate	Dow 300-15	920414-06	0.0067	0.0066	0.0066	0.0063	0.0062
1/2" Plate	Dow 300-15	920414-08	0.0067	0.0067	0.0066	0.0062	0.0062

AVERAGE OVERALL SHRINKAGE VALUES FOR : (inch/inch)

	3/4" Plates	1/2" Plates
Dow 300-4	0.0065	0.0065
Dow XU7-5.5	0.0064	0.0065
Dow300-6	0.0063	0.0065
Dow 300-15	0.0063	0.0065

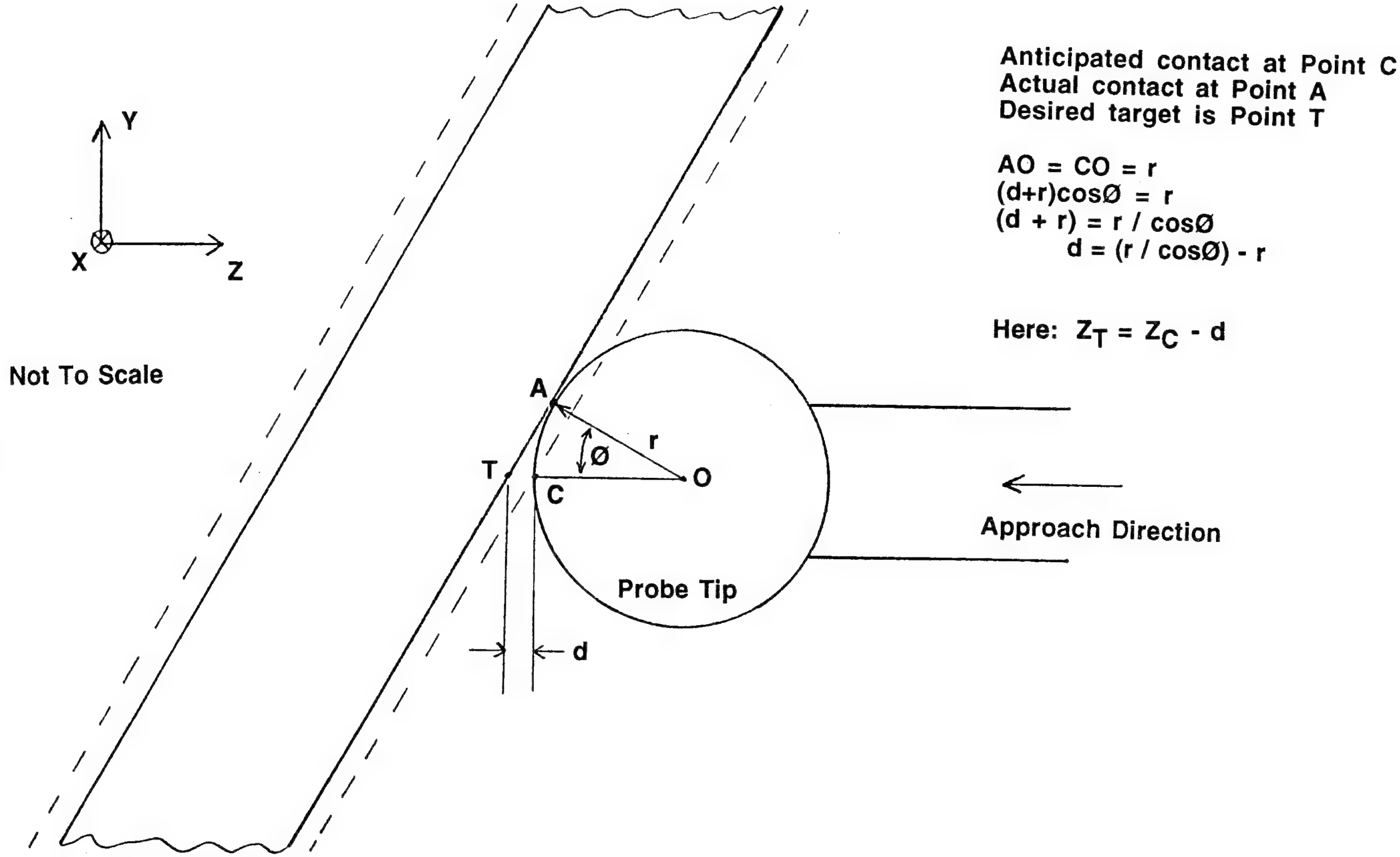


Figure 29. Ball Tangency Error Compensation

actual. The applied correction was to further translate the coordinates the additional distance "d." This correction was made during data reduction instead of internally by the CMM because of potential programming difficulties, CMM scheduling, and the fact that the correction was simple to do during the data reduction.

Once the cone and cone mold data were in PATRAN, the ball tangency error was corrected. The correction entailed generating lines through the "C" data points, finding the local angles required at the "C" data points, calculating the distance "d" required, and generating the new coordinates of the intended target points "T" (Figure 29). Once this was done, lines were generated through the new data points on the outer surface, and the normal thicknesses from the inside surface points to these lines were calculated. Typical thickness results are shown in Figure 30.

The overall dimensions of the cone and cone mold were found in much the same manner as in the flat panels and mold. Length measurements were calculated from differences in Y coordinates between points on the aft edge surface and points on the forward faces of the forward tabs. The nose face of the cone was not used because it was not a molded surface, but a machined or sawed surface. Additionally, the cone mold did not have a corresponding nose surface. Table 12 shows the overall lengths for the dimensionally mapped cones. Table 13 shows the calculated shrinkage values.

3.2.3.3 Data from Separate Mold Halves

Care was taken to establish reference frames on the mold halves such that the data obtained from one half were correctly oriented with data obtained from the other half. In theory this was a sound approach, but in practice some adjustments were required. Review of the mold data showed that the parting plane points from the core half of each mold were located internal to the plane defined by the cavity half parting plane points. In essence the data indicated that the mold halves were compressed together further than physically possible. This was attributed to the fact that the primary planes are best fit to points on a machined surface, and the best fit was different for the two halves. On a panel only one primary plane was defined,

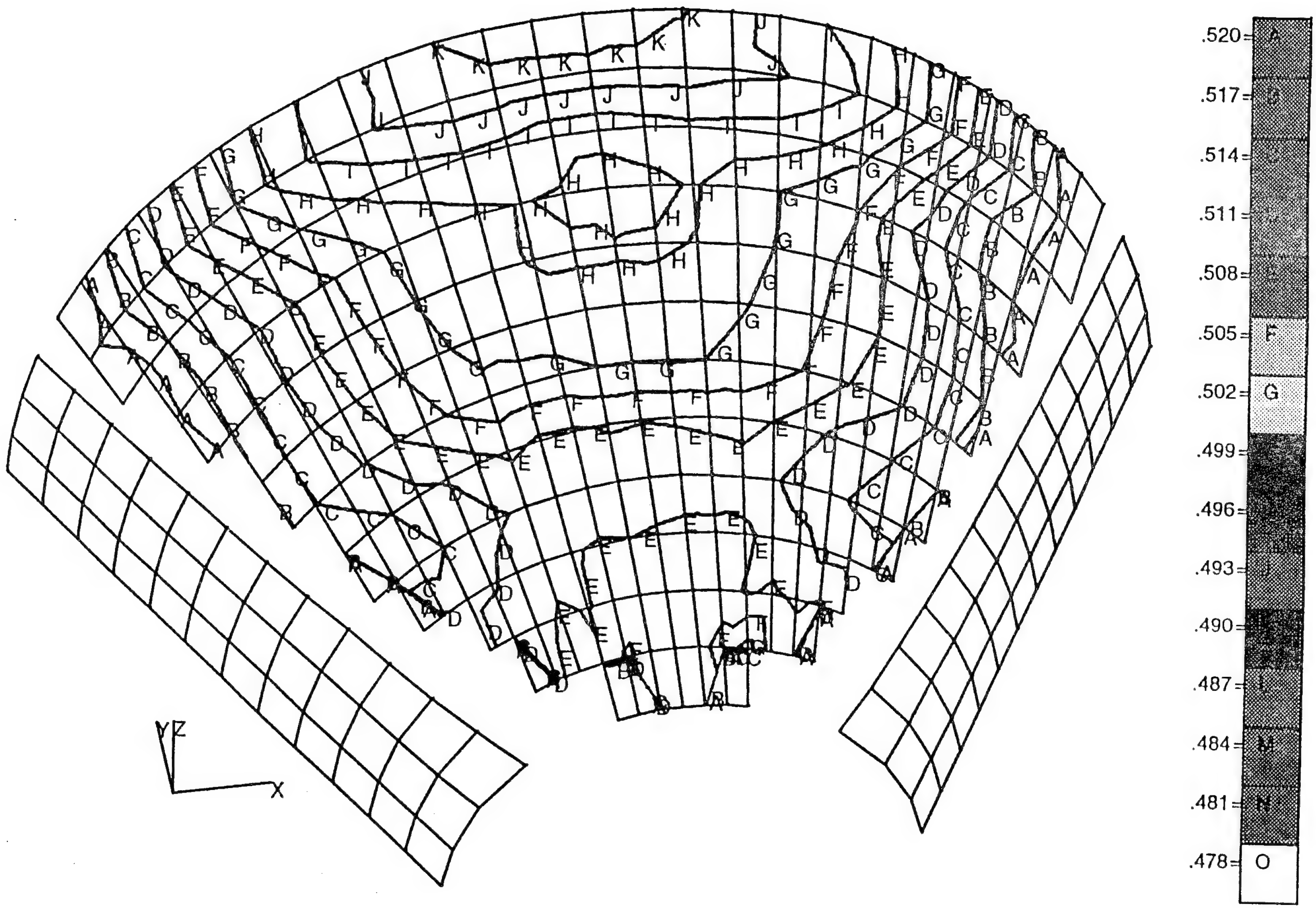


Figure 30. Typical Cone Thickness Results

Table 12. Conical Panels, Overall Dimensions

(Measurement Tolerance = 0.0001", from DM specs)

	Panel Description	Resin Description	Panel ID	Port Side Length Lp (in.)	Stbd Side Length Ls (in.)
	1/2" Cone Mold			12.0007	12.001
Jn-packed	1/2" Cone	Dow 300-4	920422-01	11.7884	11.7790
Packed	1/2" Cone	Dow 300-4	920422-02	11.9179	11.9240
Packed	1/2" Cone	Dow 300-4	920422-04	11.9114	11.9219
Packed	1/2" Cone	Dow 300-4	920422-05	11.9256	11.9129
Jn-packed	1/2" Cone	Dow XU7-5.5	920421-01	11.7997	11.7722
Packed	1/2" Cone	Dow XU7-5.5	920421-03	11.9224	11.9305
Packed	1/2" Cone	Dow XU7-5.5	920421-04	11.9387	11.9402
Packed	1/2" Cone	Dow XU7-5.5	920421-05	11.9274	11.9320
Jn-packed	1/2" Cone	Dow 300-6	920421-01	11.7920	11.7908
Packed	1/2" Cone	Dow 300-6	920421-03	11.9196	11.9202
Packed	1/2" Cone	Dow 300-6	920421-04	11.9162	11.9268
Packed	1/2" Cone	Dow 300-6	920421-05	11.9236	11.9239
Packed	1/2" Cone	Dow 300-15	920421-05	11.9347	11.9232
Packed	1/2" Cone	Dow 300-15	920421-06	11.9281	11.9207
Packed	1/2" Cone	Dow 300-15	920421-07	11.9256	11.9239

	Lp (in.)	Ls (in.)
AVERAGE(All Packed Cones)	11.9243	11.9250
STDEV(All Packed Cones)	0.0076	0.0069
AVERAGE - Packed Only (Dow 300-4)	11.9183	11.9196
STDEV(Dow 300-4)	0.0071	0.0059
AVERAGE - Packed Only (Dow XU7-5.5)	11.9295	11.9342
STDEV(Dow XU7-5.5)	0.0084	0.0052
AVERAGE - Packed Only (Dow 300-6)	11.9198	11.9236
STDEV(Dow 300-6)	0.0037	0.0033
AVERAGE - Packed Only (Dow 300-15)	11.9295	11.9226
STDEV(Dow 300-15)	0.0047	0.0017

Table 13. Conical Panels, Overall Shrinkage Values

(Shrinkage Tolerance = 0.0002 inch/inch, from DM specs)

SHRINKAGE = [Mold Dimension - Part Dimension] / [Mold Dimension]

	Panel Description	Resin Description	Panel ID	Port Side Shrinkage (inch/inch)	Stbd Side Shrinkage (inch/inch)
Un-packed	1/2" Cone	Dow 300-4	920422-01	0.0177	0.0185
Packed	1/2" Cone	Dow 300-4	920422-02	0.0069	0.0064
Packed	1/2" Cone	Dow 300-4	920422-04	0.0074	0.0066
Packed	1/2" Cone	Dow 300-4	920422-05	0.0063	0.0073
Un-packed	1/2" Cone	Dow XU7-5.5	920421-01	0.0167	0.0191
Packed	1/2" Cone	Dow XU7-5.5	920421-03	0.0065	0.0059
Packed	1/2" Cone	Dow XU7-5.5	920421-04	0.0052	0.0051
Packed	1/2" Cone	Dow XU7-5.5	920421-05	0.0061	0.0057
Un-packed	1/2" Cone	Dow 300-6	920421-01	0.0174	0.0175
Packed	1/2" Cone	Dow 300-6	920421-03	0.0068	0.0067
Packed	1/2" Cone	Dow 300-6	920421-04	0.0070	0.0062
Packed	1/2" Cone	Dow 300-6	920421-05	0.0064	0.0064
Packed	1/2" Cone	Dow 300-15	920421-05	0.0055	0.0065
Packed	1/2" Cone	Dow 300-15	920421-06	0.0060	0.0067
Packed	1/2" Cone	Dow 300-15	920421-07	0.0063	0.0064

AVERAGE LENGTH SHRINKAGE VALUES
BY MFI, PACKED CONES ONLY (inch/inch)

	1/2" Cones
Dow 300-4	0.0068
Dow XU7-5.5	0.0057
Dow300-6	0.0066
Dow 300-15	0.0062

and all data from the panel were taken relative to the one reference frame. On the molds a primary plane was found for each half, and, hence, two separate reference frames were generated. An adjustment was in order. The approach taken in 1991 was to translate, normal to the parting plane, all data points from one half until the parting plane points became as coincident as possible without the parting planes penetrating one another.

The approach used in 1991 was used during the initial stages of the 1992 DM effort. However, during evaluation of data from the 1992 DM effort, some inconsistencies were found. It was known that the cone mold had been scratched and then polished between the two DM efforts. Therefore, slightly thicker cones and a slightly thicker cone mold cavity were expected. The cones were mapped first, and indeed there was an increased thickness where the polishing took place. However, when the 1991 parting plane point adjustment was applied to the cone mold data, reduced rather than increased thickness was computed for the cone mold cavity as compared to the 1991 data. After checking the data and adjustments made for both efforts, it was decided to remap the cone mold with external tooling spheres attached.

3.2.3.4 Use Of Tooling Spheres

Three tooling spheres were attached to the external surfaces of each mold half (Figure 31, only two spheres are seen here, the third is hidden from view). The tooling spheres are calibration balls precisely ground to within 0.000005 inch of perfect roundness, therefore allowing the sphere centers to be precisely calculated repeatably and accurately. The core half of the mold was mapped as before, except that the CMM also contacted five points on each of the three sphere surfaces, and calculated the three sphere centers relative to the core frame of reference. This produced a core data set that contained the mapped data points and the core sphere centers. The cavity half was mapped in a similar fashion, producing a cavity data set that contained the mapped data points and the cavity sphere centers.

The mold was then put together (Figure 32, two of the spheres are hidden from the view) as it would be for molding, and the six centers of the tooling spheres were calculated relative to a single reference frame. The distances from each of the core sphere

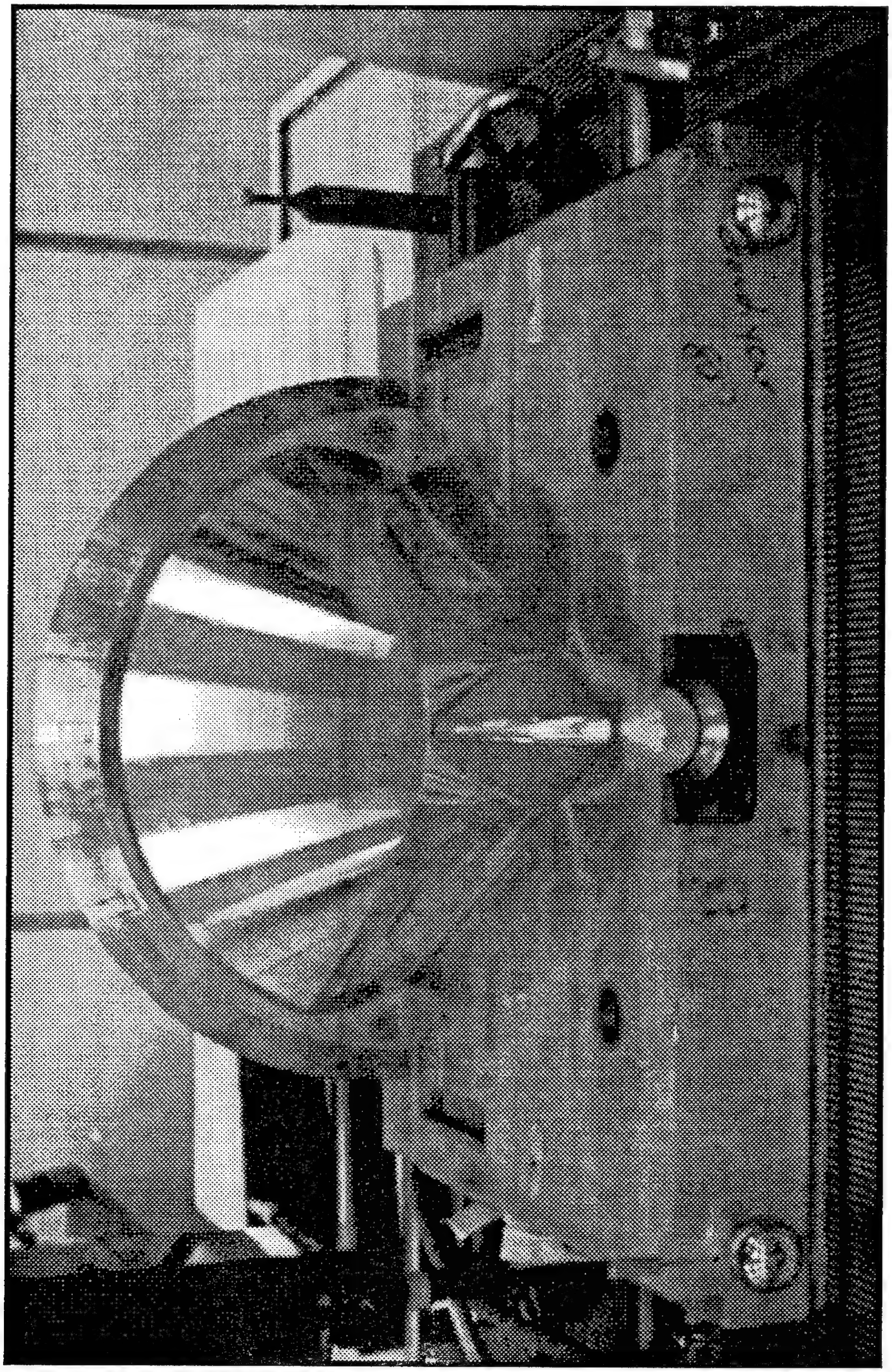


Figure 31. Core Half of Cone Mold with Tooling Spheres.

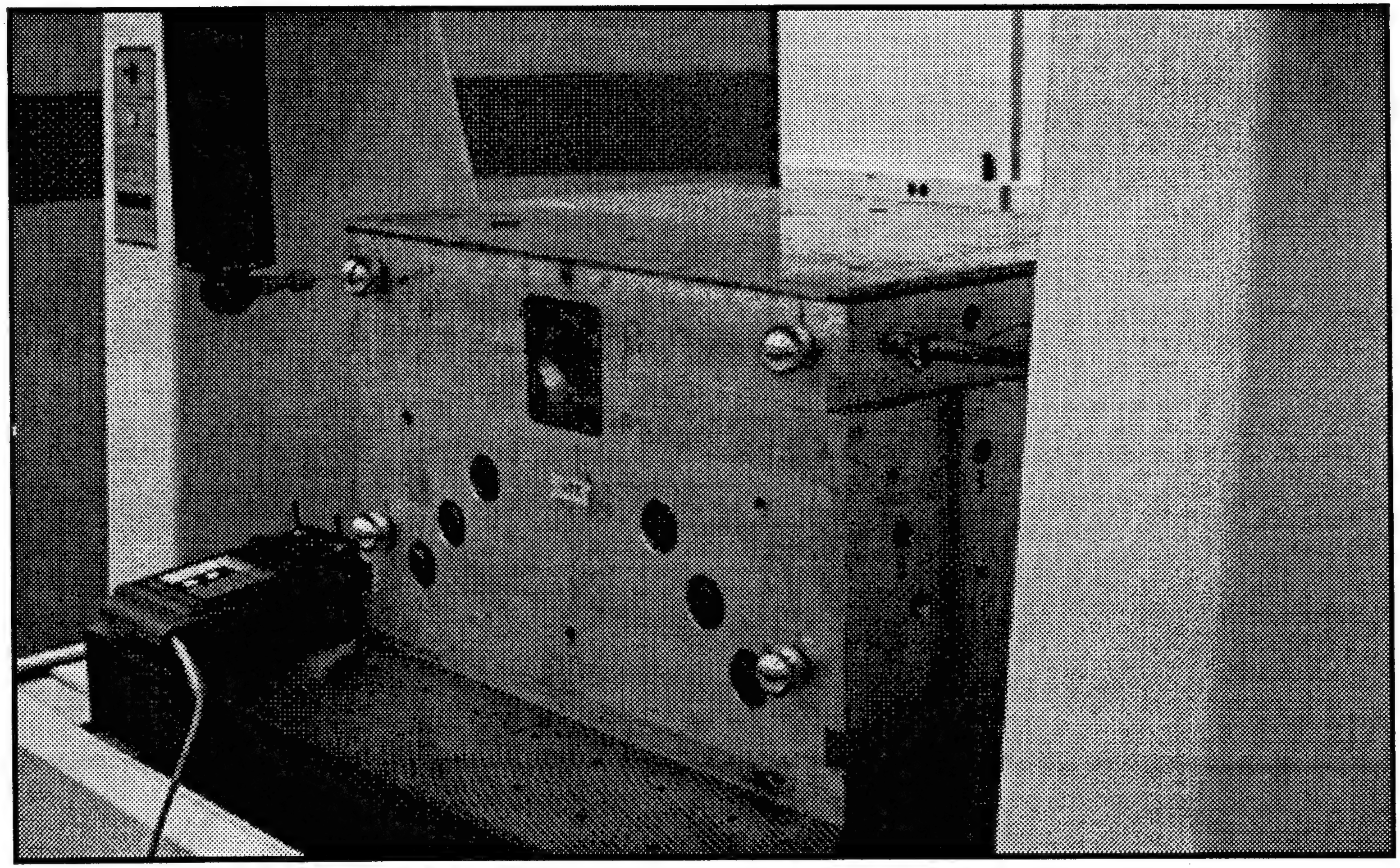


Figure 32. Closed Cone Mold with Tooling Spheres.

centers to each of the cavity sphere centers was calculated. These "closed-mold distances" were used to bring the separate core and cavity frames of reference into alignment

When the separate core and cavity data sets were loaded together into PATRAN, it was found that the distances between the core sphere centers and the cavity sphere centers was slightly different than the "closed-mold distances." The cavity data set was translated relative to the core data set until the distances between core and cavity spheres matched the "closed-mold distances."

When the tooling sphere parting plane adjustment was made, it was found that the parting plane points did not "pierce-through" each other. In fact, there was a slight gap (0.001 - 0.005 inch) between five of the six sets of parting plane points. The gaps are attributed to imperfections such as unobserved high spots on the parting planes of the core and/or the cavity.

The flat plate mold was also dimensionally mapped using the tooling spheres. All mold thickness data and all shrinkage data reported here were based on the tooling sphere parting plane adjustment, not on the method used in 1991.

Although the imperfect 1991 parting plane adjustment brought the validity of the 1991 DM data into question, results of the 1992 DM effort (using tooling spheres) showed the same trends and magnitudes of shrinkage. This indicated that the errors in the values of the 1991 data were slight, and that the general approach used in applying the 1991 data to the CFT and CFT mold design was still sound. A lesson learned was that in combining two separate sets of data, precise external surfaces need to be used as reference points during the data acquisition stage of dimensional mapping.

3.3 Results

Table 11 shows that the average values for overall shrinkage (i.e., shrinkage in length and width) for all flat panels are very consistent at approximately 0.0065 inch/inch. This value agrees

well with data sheets of resin vendors which state a shrinkage factor for polycarbonate of 0.006 inch/inch. The overall shrinkage in the flat panels does not vary greatly; the maximum encountered is 0.0069 inch/inch, and the minimum is 0.0058 inch/inch.

Two trends were observed in the data in Table 11. One is that the shrinkage tends to be greater at greater distances from the gate. This is logical because the portion of the panel close to the gate will feel the effects of the packing pressure for the longest time in a uniformly heated mold. The overall width shrinkage at the arch end of the plates is approximately 0.0005 inch/inch greater than the overall width shrinkage at the gate end of the plates. The arch end width measurement is approximately 22 inches further from the gate. Another trend is that the shrinkage appears to decrease slightly (in most cases) as the MFI increases. It should be noted, though, that the decrease in shrinkage is very slight.

The observed through-the-thickness shrinkage in the flat panels was much higher than the overall shrinkage (Figures 33 and 34). Observed values along the centerline of the panels ranged from 0.020 - 0.062 inch/inch, generally increasing with distance from the gate. This varying shrinkage was also observed in the conical panels and was not unexpected. The values for through-the-thickness shrinkage at a given distance from the gate only varied by a maximum of approximately 0.008 inch/inch over the whole population of flat panels.

Figures 35 to 37 show the average through-the-thickness shrinkage along the centerline for panels grouped by MFI. These data show that shrinkage tends to decrease slightly with an increase in MFI. Also, the 1/2-inch panels have slightly higher shrinkage values than the 3/4-inch panels. The decrease in shrinkage toward the "arch" of the flat panels (at 16 - 22 inches from the gate) can be attributed to the panel geometry. The sills and arch area of the flat panels are thickened, thereby creating a path for the packing pressure around the perimeter of the panels. This allows for a more complete packing of the panel edges.

The overall shrinkage values for the conical panels are shown in Table 13. Considering only the packed cones, the observed values are again very close to industry accepted values for polycarbonate, approximately 0.006 inch/inch. The average values for the conical panels range

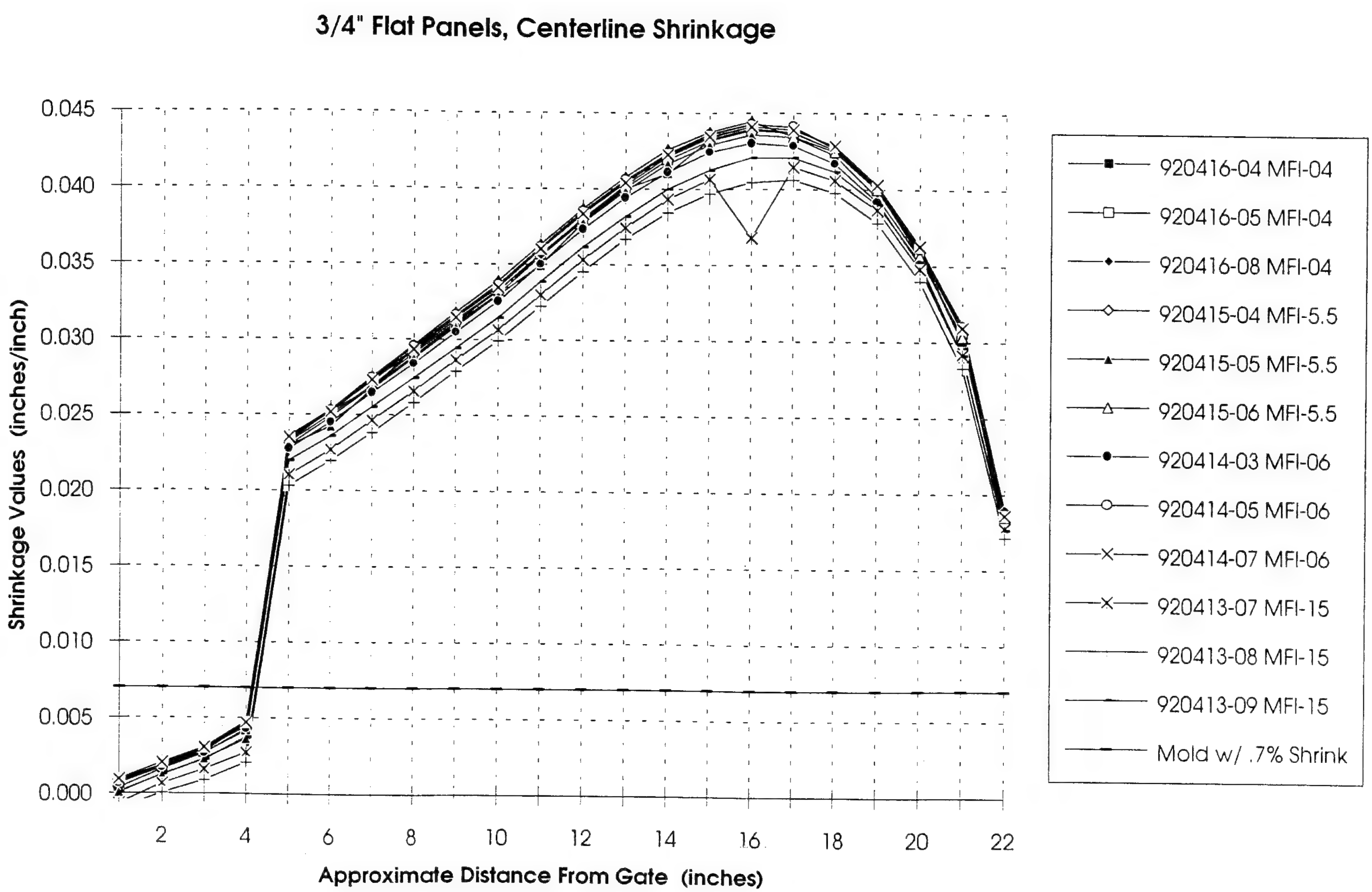


Figure 33. 3/4-Inch Flat Panels, Centerline Shrinkage.

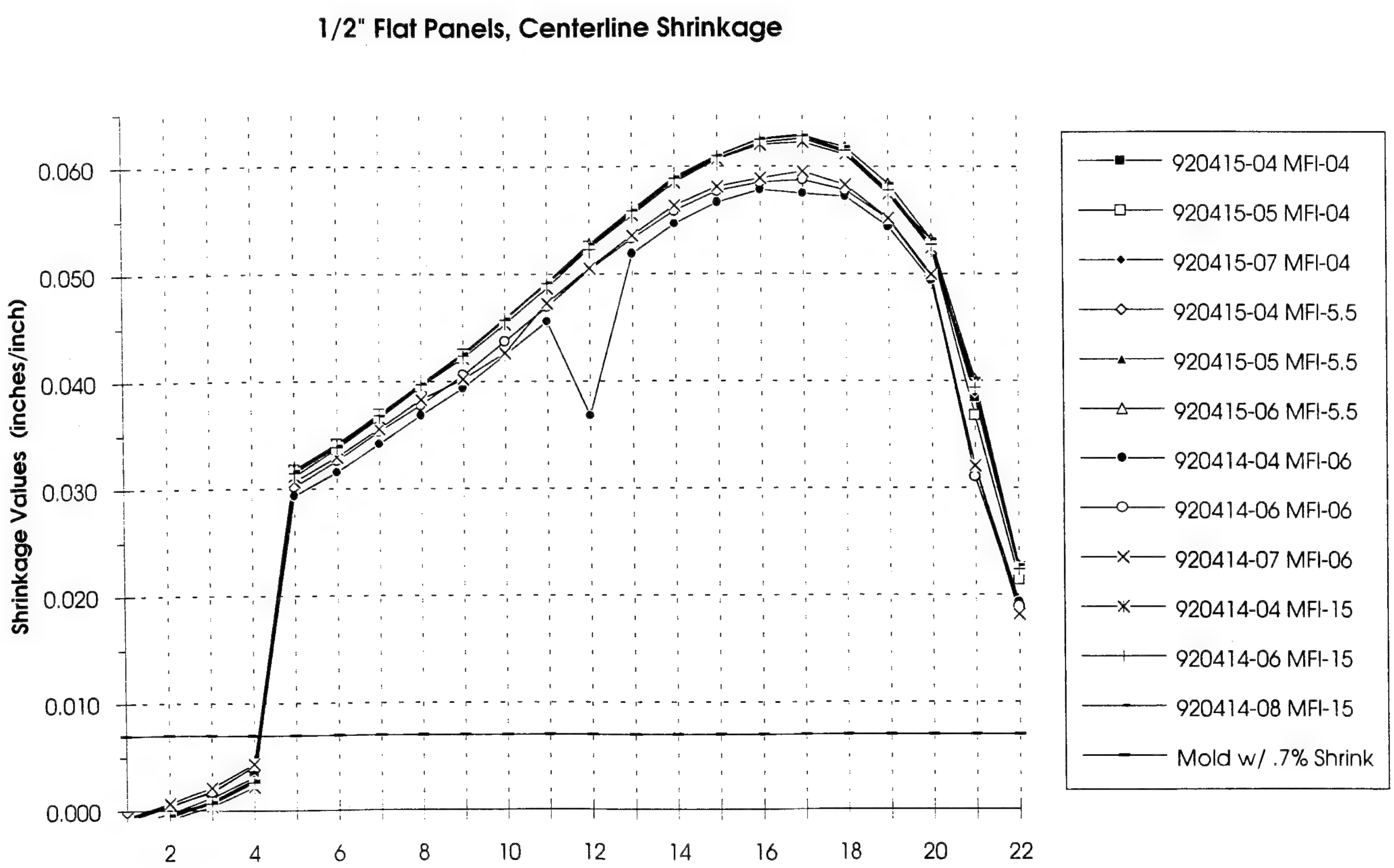


Figure 34. 1/2-Inch Flat Panels, Centerline Shrinkage.

3/4" Flat Panels, Averaged Centerline Shrinkage

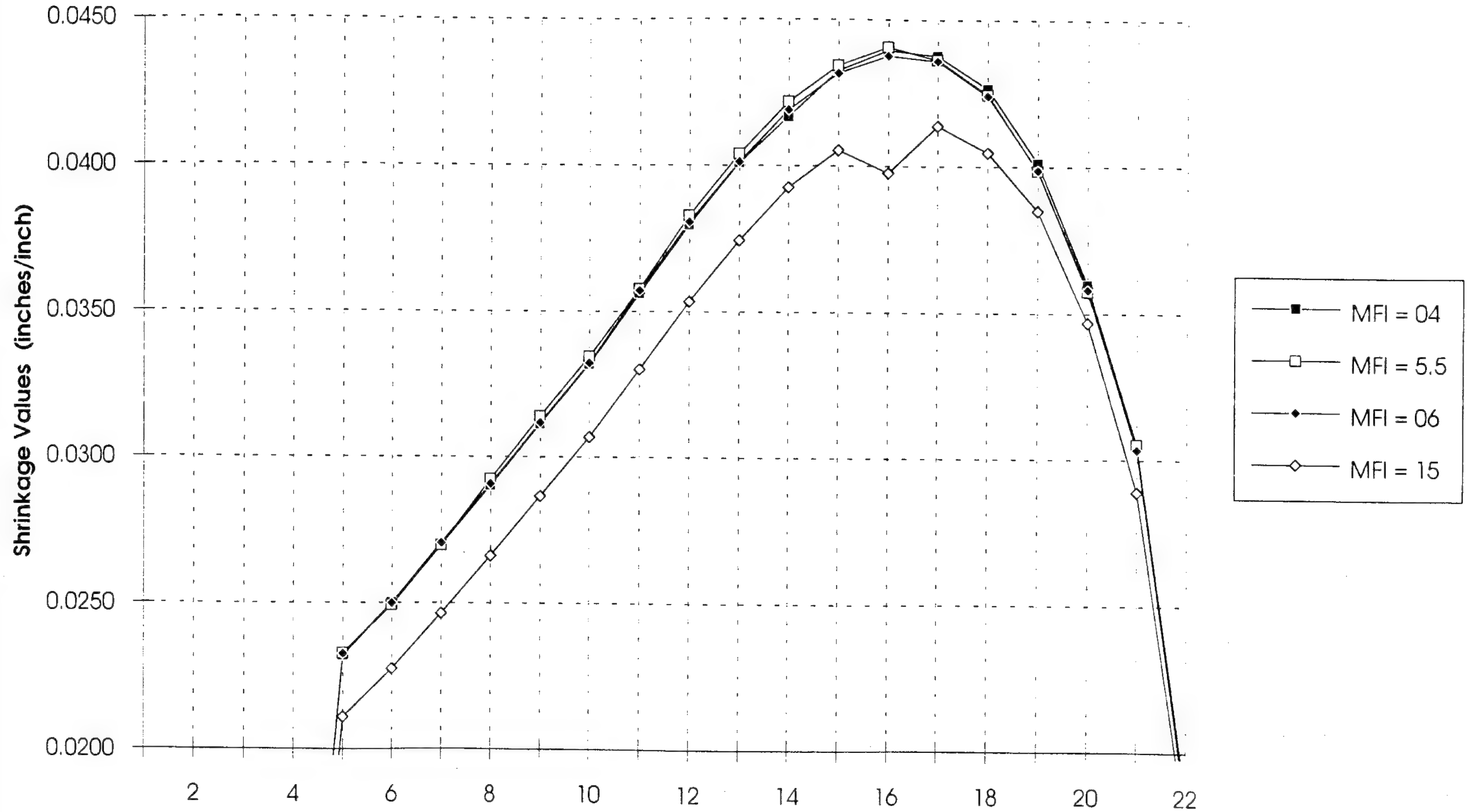


Figure 35. 3/4-Inch Flat Panels, Averaged Centerline Shrinkage.

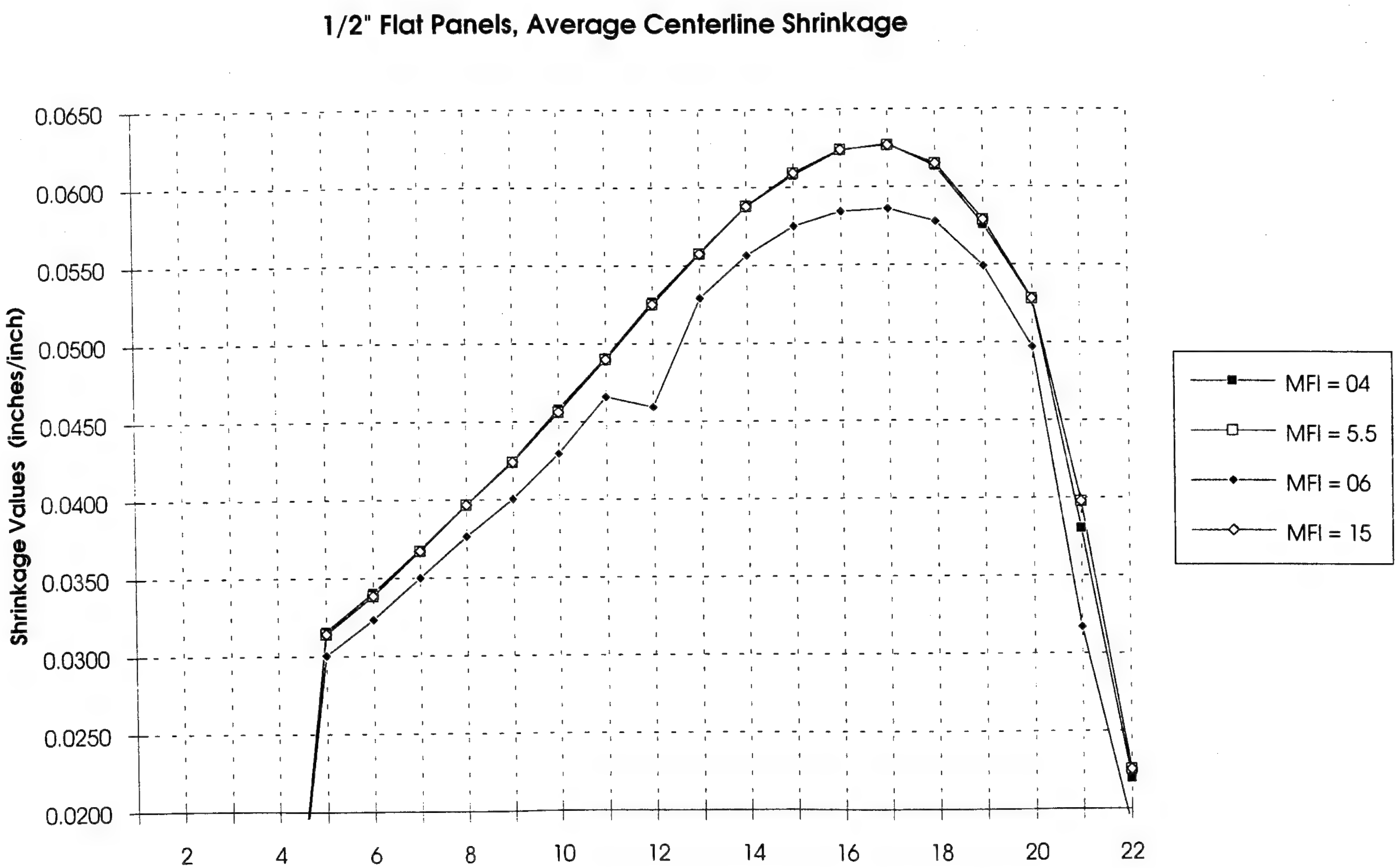


Figure 36. 1/2-Inch Flat Panels, Averaged Centerline Shrinkage.

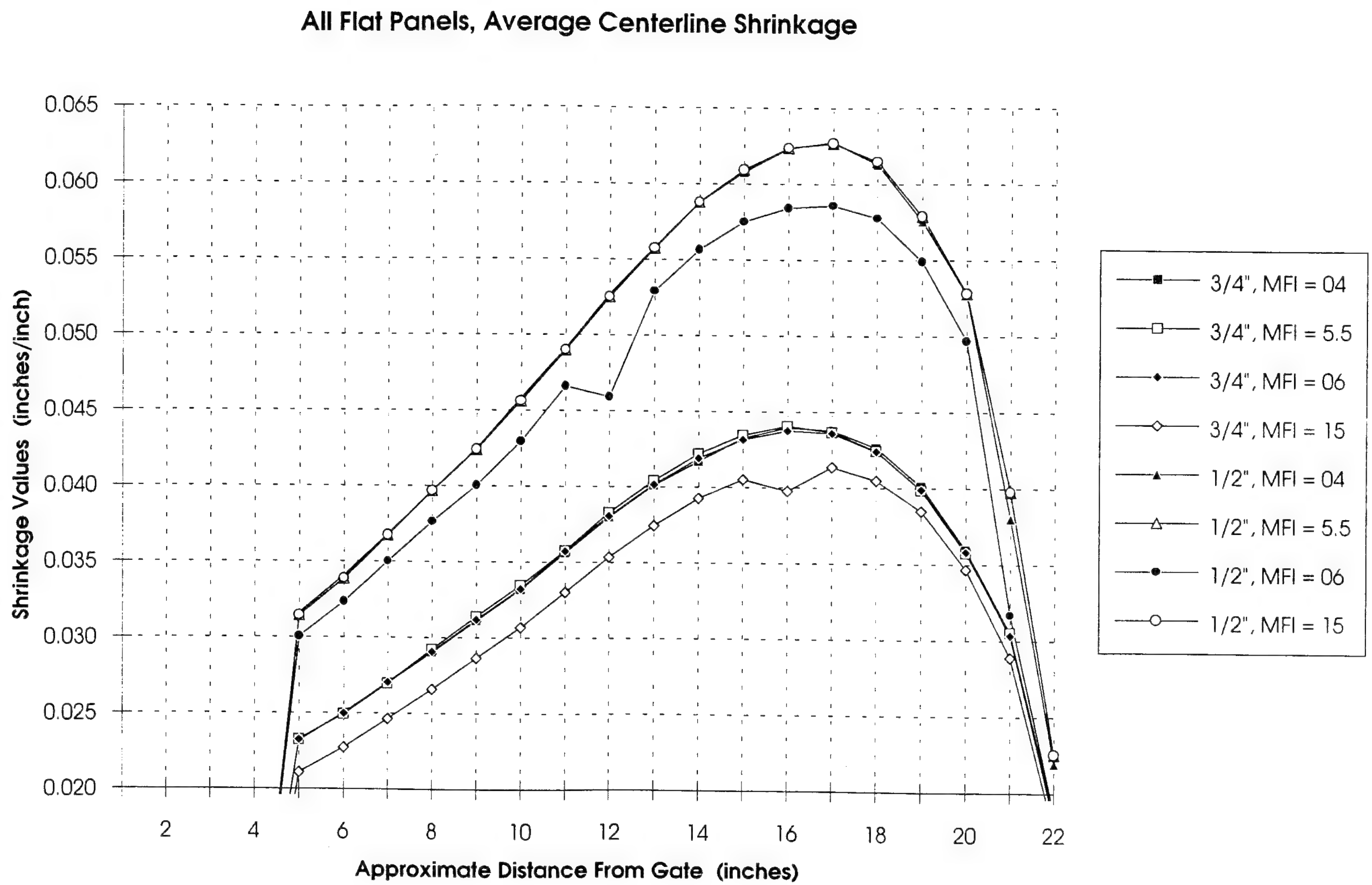


Figure 37. All Flat Panels, Averaged Centerline Shrinkage

from 0.0057 to 0.0068 inch/inch. For the Dow 300-xx resins the shrinkage decreases slightly as the MFI increases. The Dow XU7-5.5 had the least overall shrinkage than any of the Dow 300-xx resins and, hence, did not follow the trend of decreasing shrinkage with increasing MFI.

Figures 38 and 39 are plots of centerline shrinkage vs. distance from the gate for the packed conical panels. There is a varying shrinkage as the distance from the gate changes. The range of values is from 0.005 inch/inch to 0.048 inch/inch. Figure 39 shows that shrinkage was greatest in the Dow 300-4 resin and least in the experimental resin Dow XU7-5.5.

An exercise was conducted to confirm the thickness values calculated from CMM data by cutting up one of the dimensionally mapped cones and using a micrometer to measure the thickness at a group of six points (Table 14). Three of the six points were located near the centerline and three near the port sill edge. Five trials of micrometer readings were made, and the results compared with the values obtained by dimensional mapping. The measurement values obtained by dimensional mapping agree well with the micrometer measurements. The greatest difference between the average micrometer readings and the dimensional mapping values was 0.0006 inch. Differences between the desired and actual locations of the micrometer placement is most likely the cause of the difference between the values obtained by the two methods. The measurement tolerances listed in Table 9 are considered confirmed by the micrometer measurement exercise.

3.4 Conclusions

3.4.1 Shrinkage

The results of the overall shrinkage (lengths and width) observed in the flat and conical panels show that a shrinkage factor of 0.0065 inch/inch (for lengths and width) would apply well to any of the resins used.

Shrinkage through the thickness of the panels was not only much higher than "standard" values (i.e., up to 0.062 inch/inch), it also varied with location on the panels.

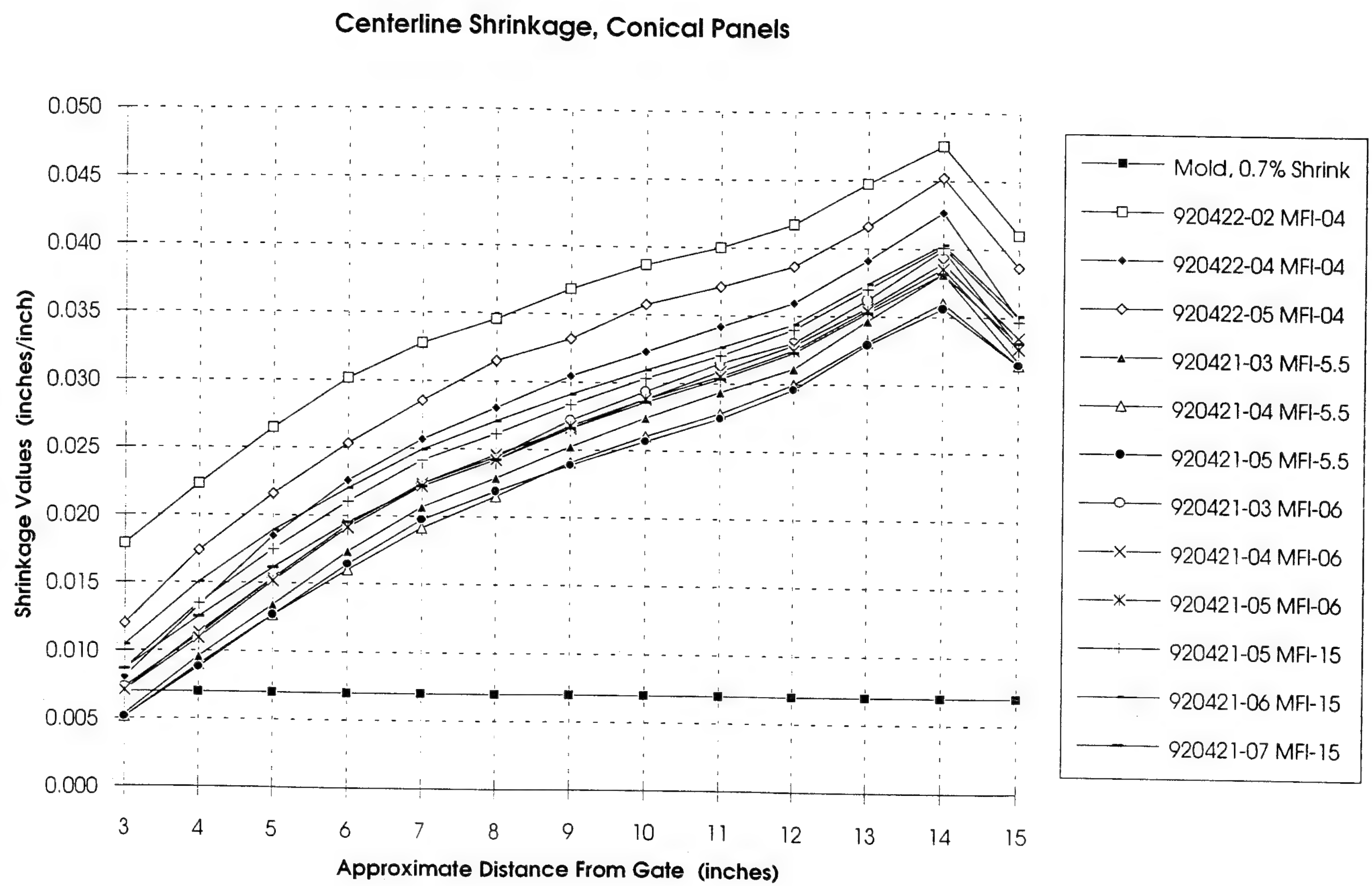


Figure 38. Conical Panels, Centerline Shrinkage

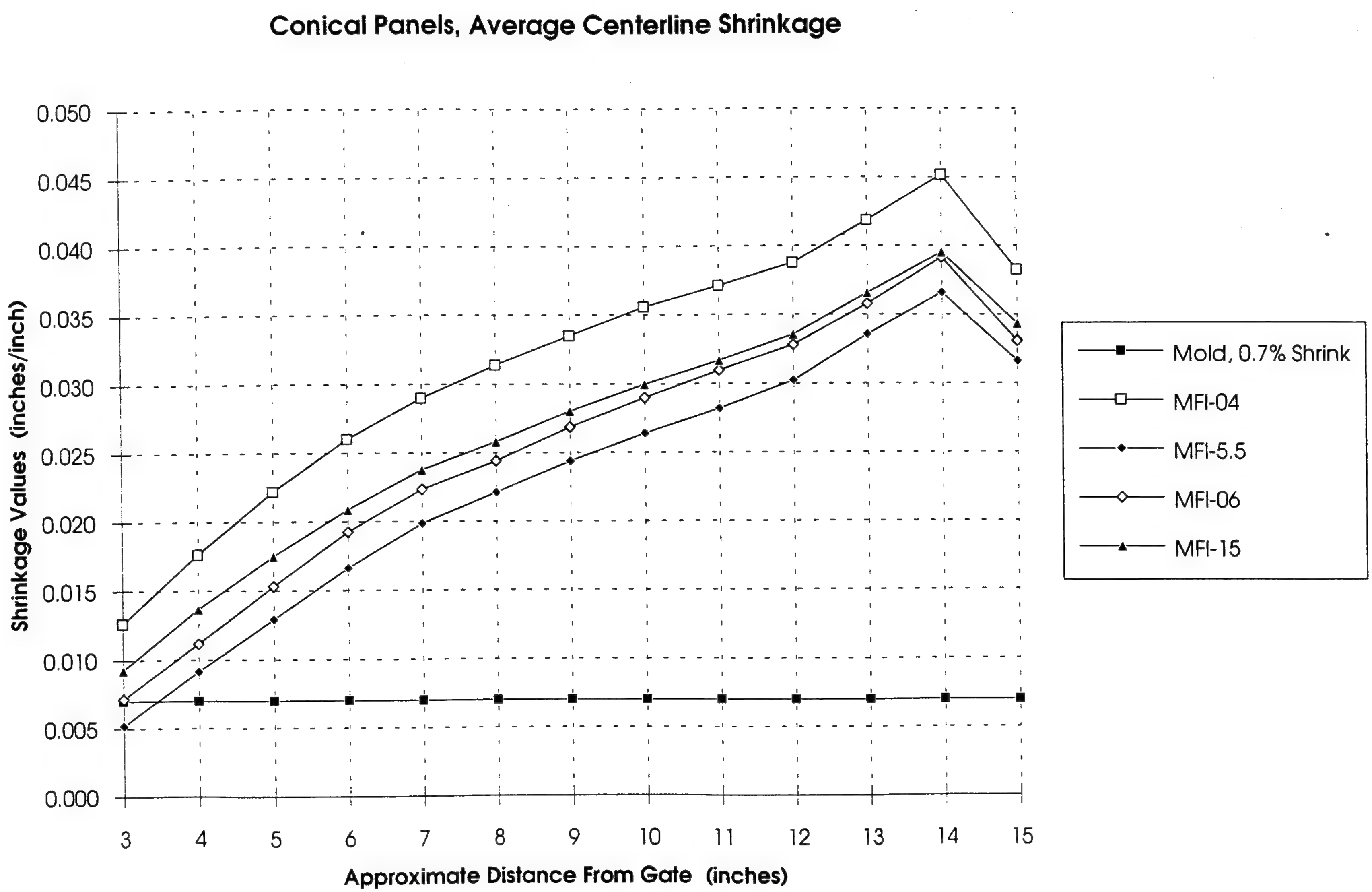


Figure 39. Conical Panels, Averaged Centerline Shrinkage

Table 14. Thickness Measurement Comparison
Micrometer vs. Dimensional Mapping

(values shown in inches)

Micrometer Measurement Trial	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
1	0.5213	0.5233	0.5200	0.4883	0.4979	0.4992
2	0.5214	0.5232	0.5199	0.4883	0.4980	0.4993
3	0.5213	0.5235	0.5202	0.4882	0.4981	0.4993
4	0.5211	0.5232	0.5201	0.4883	0.4981	0.4993
5	0.5214	0.5233	0.5202	0.4882	0.4980	0.4993
Average of 5 micrometer readings	0.5213	0.5233	0.5201	0.4883	0.4980	0.4993
Stdev of 5 micrometer readings	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000
Dimensional mapping value	0.5214	0.5227	0.5202	0.4888	0.4975	0.4990
Absolute Difference between average micrometer reading and the dimensional mapping value.	0.0001	0.0006	0.0001	0.0005	0.0005	0.0003

Point 1 located 60 degrees port of centerline, 1.25" forward of aft edge
Point 2 located 60 degrees port of centerline, 2.25" forward of aft edge
Point 3 located 55 degrees port of centerline, 0.25" forward of aft edge
Point 4 located 5 degrees port of centerline, 0.25" forward of aft edge
Point 5 located 5 degrees port of centerline, 2.25" forward of aft edge
Point 6 located 5 degrees port of centerline, 4.25" forward of aft edge

Applying an overall shrinkage factor to a part design is necessary, and typical shrinkage factors can be used when considering overall dimensions. When considering the thickness of panels, however, a compensation in mold design may be necessary to obtain desired thickness results.

Although the shrinkage varied greatly depending on distance from the gate and slightly for differences in MFI, the resultant variation in the thickness of the panels was not great. For example, at a given distance on the centerline from the gate, both 1/2-inch and 3/4-inch panels varied in thickness by a maximum of 0.002 inch within a MFI group, and by 0.004 inch when all MFIs were considered. In the conical panels the variance was a maximum of 0.004 inch within a MFI group and 0.007 inch when all MFIs were considered. This small variance indicates that injection molding produces very repeatable panels.

3.4.2 Dimensional Mapping Procedure

It was found that staging a part only once for data acquisition is highly preferable to multiple stagings. If a part must be staged more than once, extreme care must be taken to ensure that the multiple sets of data can be accurately combined.

Based on the same trends and magnitudes shown in both DM efforts, the use of a CMM to acquire data points for part measurement is a very reliable method.

The accuracy, repeatability, and automation capabilities of a CMM are very desirable in part measurement. When compared to techniques involving human manipulation of hand held instruments, the CMM is at least an order of magnitude more accurate and reliable.

Using a CMM, however, is orders of magnitude more complex and expensive than using hand held instruments. The automation capabilities cannot be realized without a potential lengthy program development period. Additionally, CMMs are definitely not portable; they require installation in a controlled environment in order to realize the accuracy and repeatability benefits.

SECTION 4
BIRDSTRIKE EVALUATION

The ability to injection mold transparency materials which maintain structural integrity during a bird impact is one objective of the FTP. A series of 18 test panels were birdstrike tested at UDRI to evaluate the impact resistance of several candidate CFT resins. Each panel was shot by a 2-pound artificial bird at a 30 degree impact angle. The birdstrike threshold of each candidate CFT material was determined by varying the impact velocity for each shot. Section 4.1 describes the CFT panels and test facilities used in this program. Analysis methods were employed to obtain additional impact data for comparative purposes. Triangulation techniques to determine the deflection-time-history response during the impact test are discussed in Section 4.2. Finite element analysis methods to simulate the birdstrike event are described in Section 4.3. Finally, results of the testing and analysis are discussed in Section 4.4.

4.1 Birdstrike Testing

A birdstrike test program was conducted at UDRI to evaluate the birdstrike resistance of panels molded utilizing an Envirotech molding machine and several candidate Dow resins. The test article was a relatively flat injection molded polycarbonate panel, depicted in Figure 40. The thickened edge sections of the panel represent a potential method for eliminating the frame used in current transparency designs. Inserts can be molded into the thickened edge regions to attach the transparency directly to the aircraft. The panel also contains a coupling region which is representative of a feature which could be used to couple a windshield and a canopy.

The polycarbonate panels that were tested and their respective molding parameters are presented in Table 15. Panels were molded from four different Dow resins, namely, XU7-5.5, 300-15, 300-6, and 300-4, for the evaluation. The testing goal was to determine if one resin was preferable over another based upon the birdstrike resistance. Both 1/2-inch and 3/4-inch thick panels were tested. Panel selection was made by the Air Force project engineer in conjunction with UDRI. Note that the panel number contains the year, month, and day on which the panel was molded.

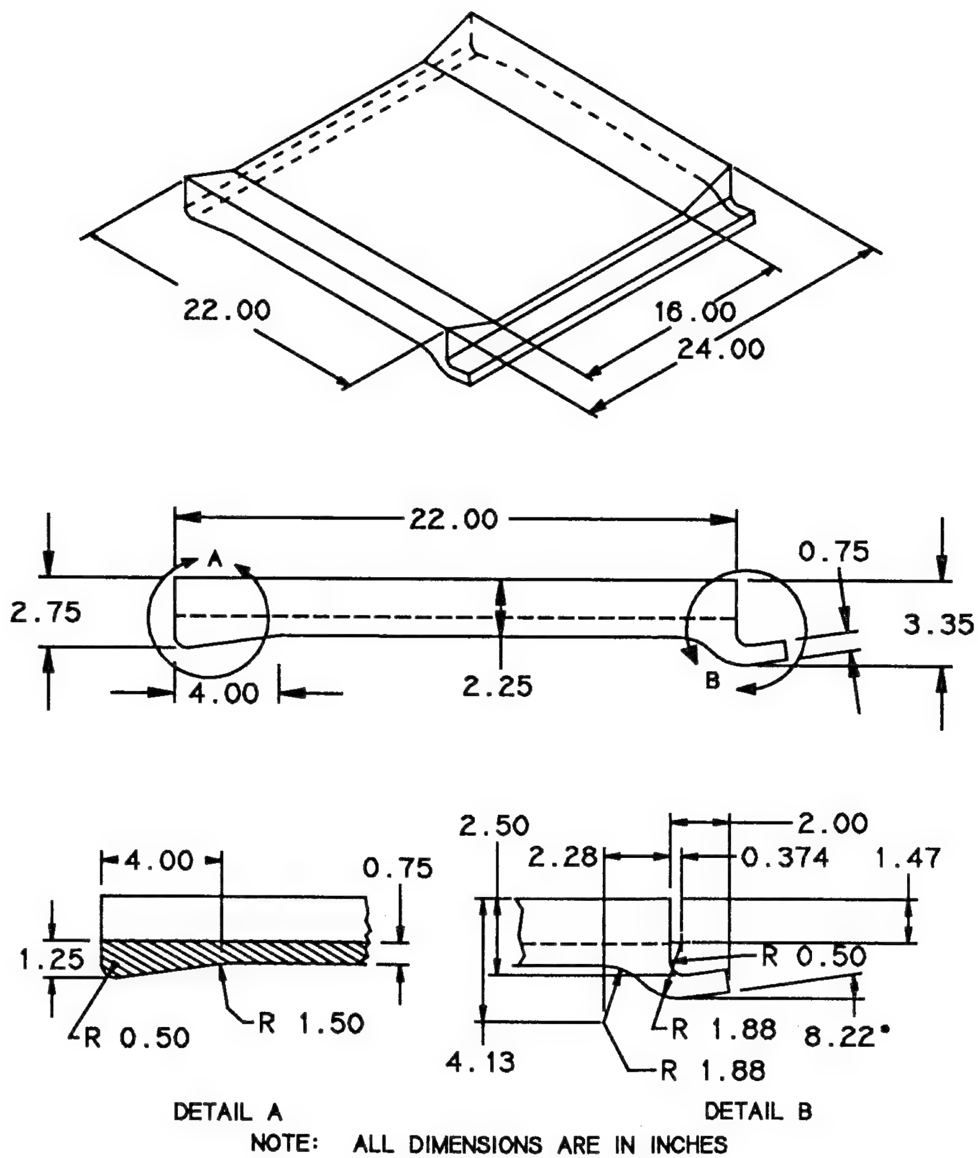


Figure 40. Injection Molded Panel Geometry.

Table 15. Panel Molding Parameters.

Shot Number	Panel Number*	Process Number	Resin	Thickness (inches)	Quality**	Melt Temp. (°F)	Ave. Mold Temp. (°F)	Injection Time (seconds)
1	920415-05	MX2054	Dow XU-5.5	1/2	2	561	212	14.42
2	920415-06	MX2054	Dow XU-5.5	1/2	2	560	217	14.64
4	920415-07	MX2054	Dow XU-5.5	1/2	3	560	217	14.38
6	920414-04	MX2053	Dow 300-15	1/2	6	550	205	7.00
7	920414-05	MX2053	Dow 300-15	1/2	5	544	204	7.90
8	920414-08	MX2053	Dow 300-15	1/2	2	560	213	8.50
9	920415-05	MX2050	Dow XU-5.5	3/4	4	560	209	14.1
10	920415-06	MX2050	Dow XU-5.5	3/4	4	560	209	14.9
11	920415-07	MX2050	Dow XU-5.5	3/4	3	560	208	16.9
12	920413-07	MX2049	Dow 300-15	3/4	5	573	204	7.53
13	920413-09	MX2049	Dow 300-15	3/4	4	573	216	7.50
14	920413-10	MX2049	Dow 300-15	3/4	6	573	217	7.98
15	920414-05	MX2048	Dow 300-6	3/4	5	560	212	12.84
16	920414-07	MX2048	Dow 300-6	3/4	5	561	217	12.50
17	920416-05	MX2047	Dow 300-4	3/4	6	561	211	14.1
18	920416-07	MX2047	Dow 300-4	3/4	6	561	214	14.6
19	920414-08	MX2048	Dow 300-6	3/4	6	560	217	12.08
20	920416-08	MX2047	Dow 300-4	3/4	5	561	211	14.1

*Panel Number: yymmdd-nn
yy = mold year mm = mold month
dd = mold day nn = panel number

**Quality is determined and specified by the Air Force after molding. (1=good, 10=bad)

Birdstrike testing to support the FTP was performed in the UDRI Impact Physics Laboratory. A 7-inch internal diameter gun was used for all tests. Plastic sabots were used to deliver an artificial bird to the target. Each panel was supported by a test fixture provided by the Air Force. The test fixture allowed for adjustments so that the panel could be positioned at the appropriate height for the gun barrel while maintaining the 30 degree impact angle. Laser timing equipment was used to compute impact velocity, and three high-speed cameras were used to record each shot. Figure 41 shows the birdstrike test setup used throughout the test program.

During testing the panels were clamped to the fixture on three sides, leaving the aft edge (coupling region) unrestrained. Rubber pads were placed between the test fixture and the panel along the clamped edges to prevent the panel from being in direct contact with the steel fixture. The support clamps were tightened until compression of the rubber pads was visible. Figure 42 shows a panel installed in the Air Force test fixture. Note that the crosses marked on the panel were for triangulation purposes and will be discussed in more detail in the next section.

Each impact test was performed in the same manner except that the bird velocity was varied. The impact location was a point near the center of the panel on the panel centerline as indicated in Figure 43. Projectiles used in the test program were 2-pound artificial birds molded from gelatin (ρ=0.034 lb_f/in^3, 10% porosity, equation-of-state of water [4]). The bird geometry was a right circular cylinder with a 3.5-inch diameter and a 6.0-inch nominal length. Minor adjustments were made to the bird length to obtain the 2-pound weight specification.

4.2 Triangulation Method for Deflection-Time Data

A method for obtaining deflection-time-history data for points on a transparency during the bird impact event has been developed by the Air Force [5]. This triangulation method determines point locations as functions of time from pairs of simultaneous high-speed film images, known pretest point locations, and known camera positions.

To obtain deflection-time-history data, at least two high-speed cameras must be positioned such that each camera views all points of interest on the target panel simultaneously. Appropriate

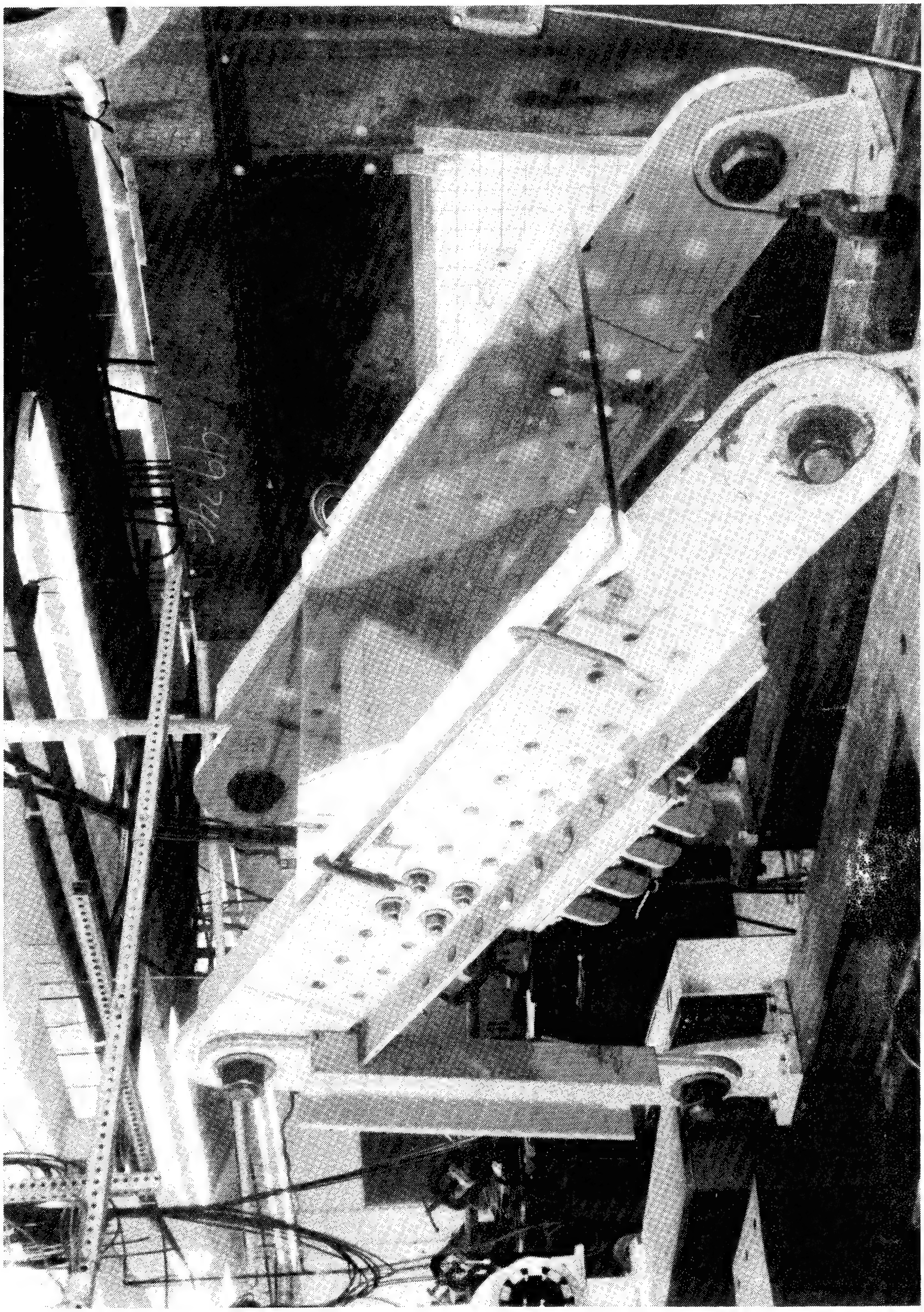


Figure 41. Birdstrike Test Setup.

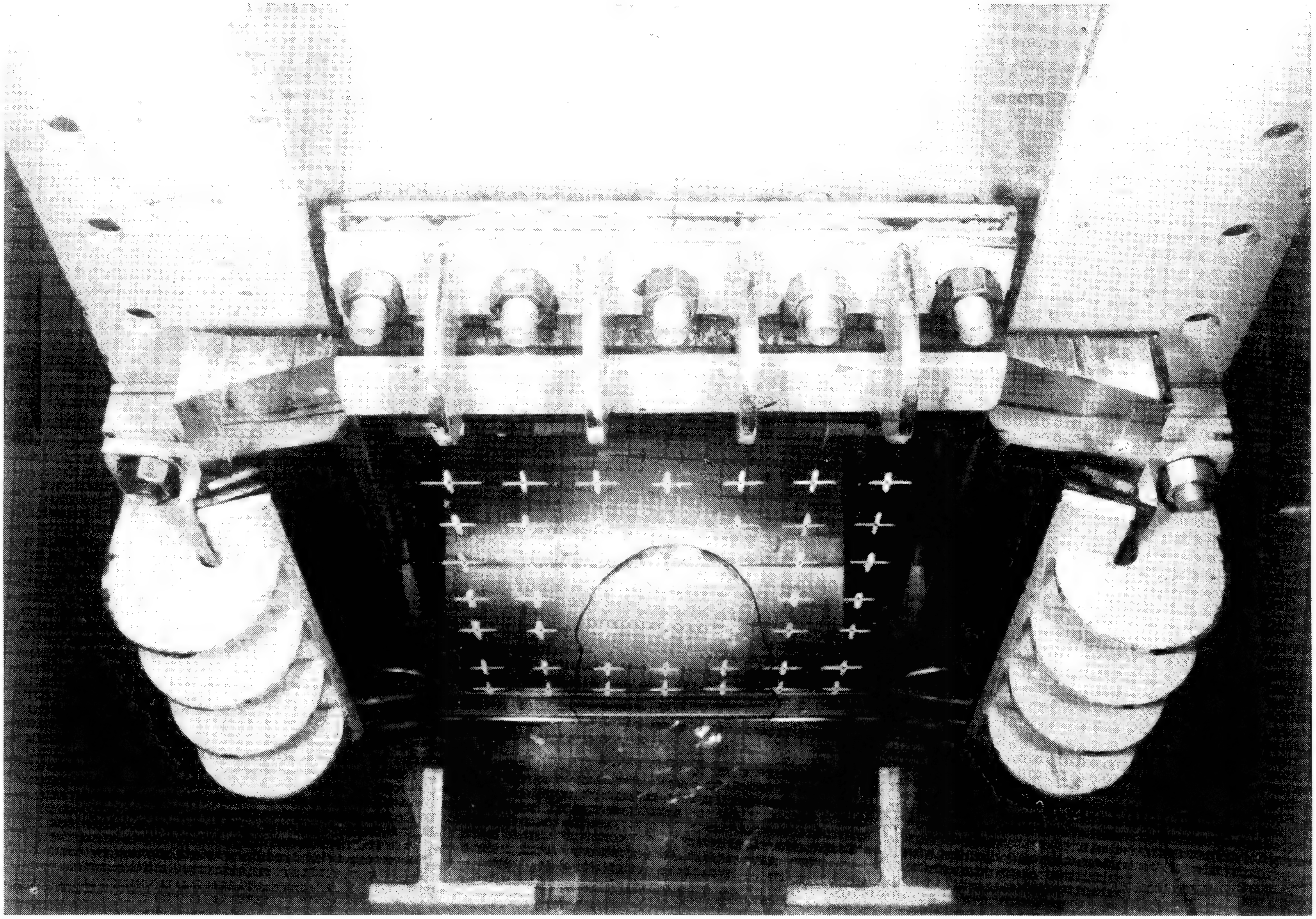


Figure 42. Panel Installation.

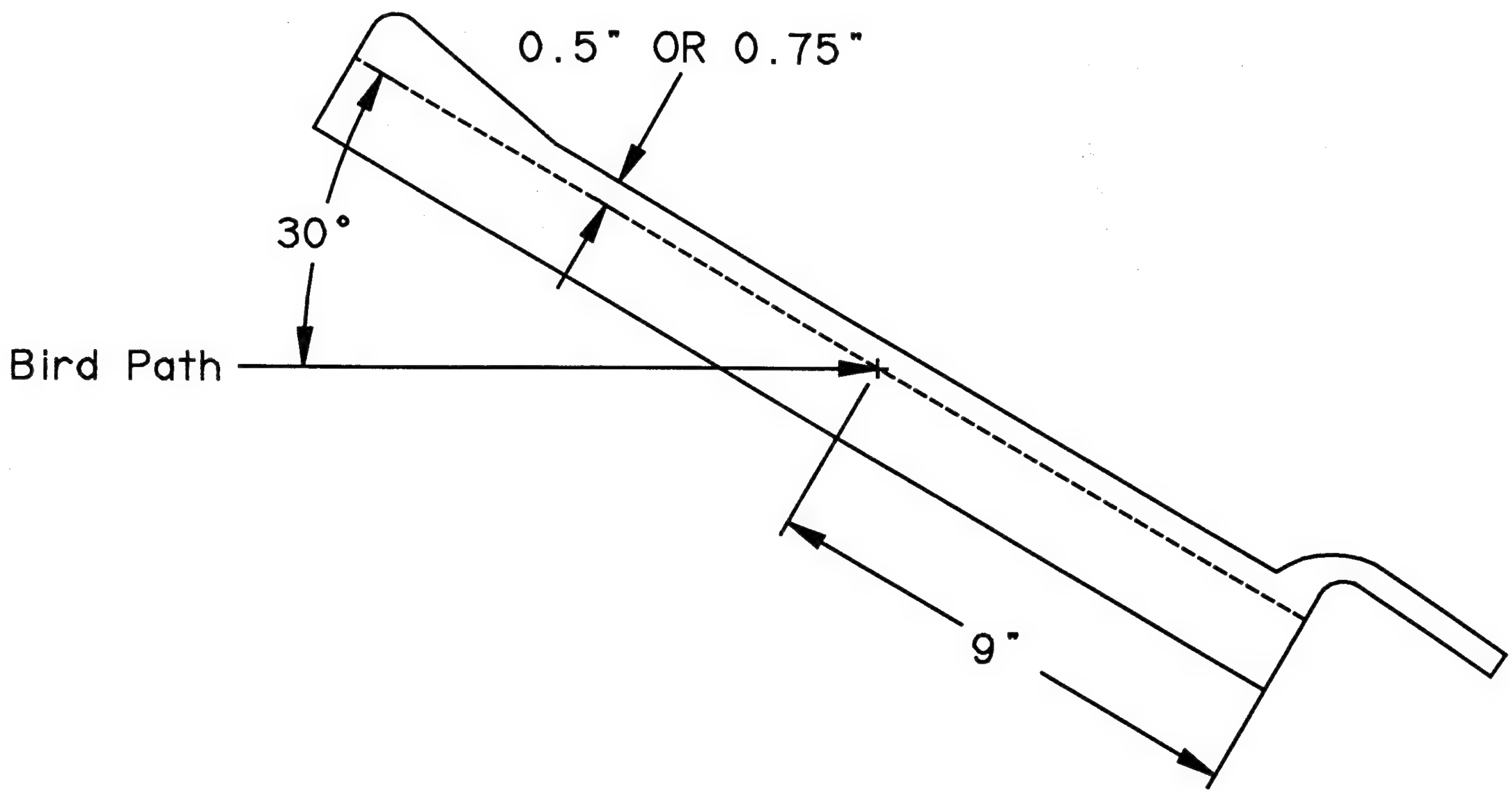


Figure 43. Impact Location.

camera positions were selected based upon light requirements, lens combinations, camera mounting sites, and camera shielding requirements. For this particular birdstrike program three, Photec IV, Rotating Prism, 16mm, high-speed, motion-picture cameras were used (at nominal frame rates of 5000 frames/second); one for determining bird pitch before impact, and two for the triangulation analysis.

To differentiate between the two cameras used in the triangulation analysis, FWD and AFT camera designations were used. Relative orientations of the triangulation cameras are depicted in Figure 44. Distances between the impact point and FWD and AFT cameras were approximately 74 inches and 108 inches, respectively. Coordinates of the camera positions relative to a three-dimensional triangulation space were measured.

Protective shielding for both cameras was obtained by clamping a 1/2-inch thick Lexan sheet to the test fixture. Originally, there was concern that the placement of the protective shielding relatively near to the test article (approximately 12 inches) would affect the triangulation data. Preliminary analyses indicated that this was not the case, although extra lighting was required to properly illuminate the panel.

Calibration data were obtained for each camera/lens/shield/projection combination to account for the magnification of the cameras, lenses, protective shielding, and projection equipment used in the birdstrike testing. A calibration film was generated by exposing several film frames with the camera positioned at various distances away from a uniform grid board (2-inch spacing). During calibration the distance between the camera and grid board was varied over a range of distances which encompassed all likely point-to-camera distances to occur during the birdstrike.

For valid calibration results the identical camera/lens/shield/projection configuration was used to obtain the calibration film and the test film. The relative spacing and inclination between the camera and the protective shielding were identical during calibration and testing.

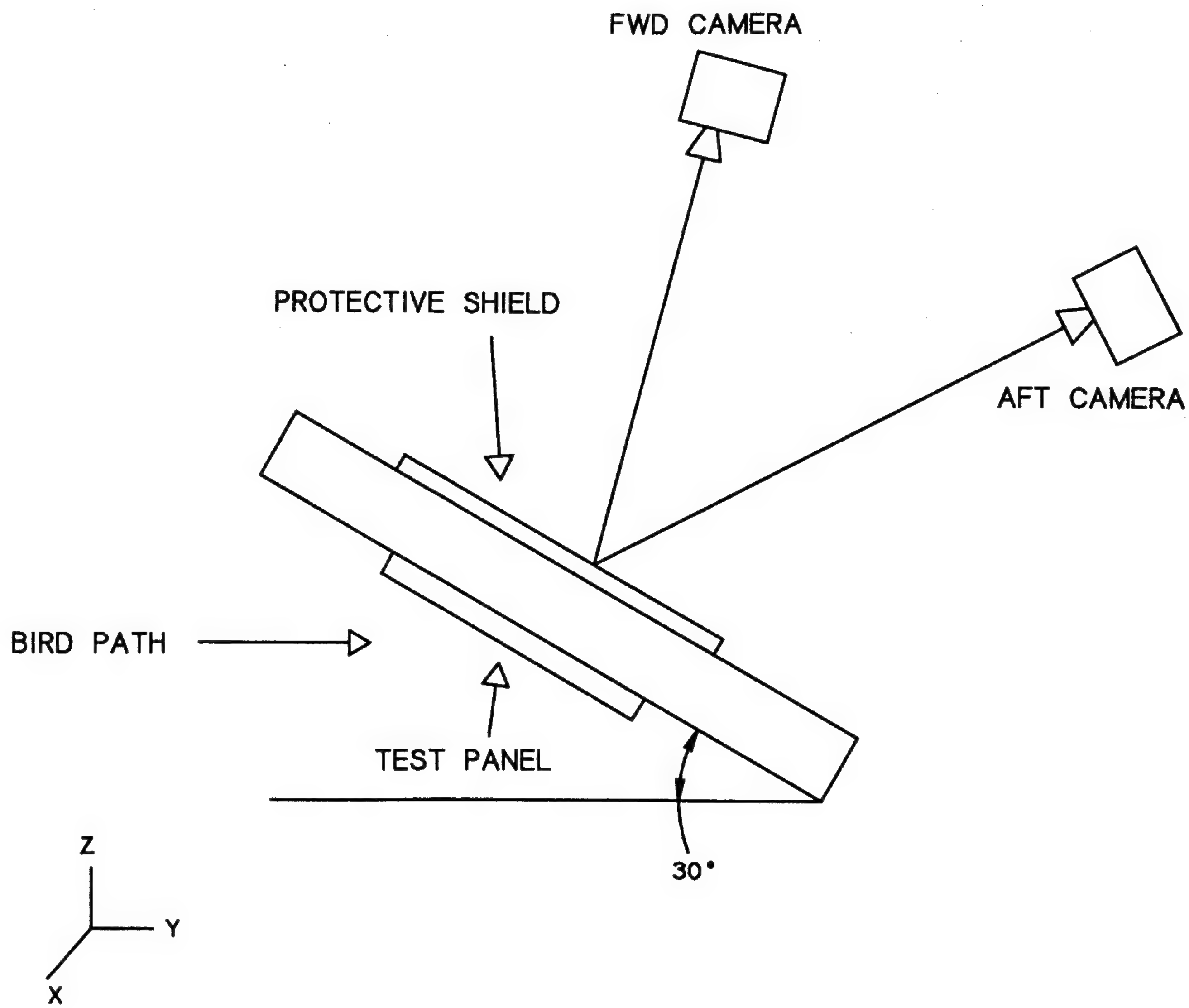


Figure 44. Triangulation Camera Orientation.

The distance and orientation between each camera and the protective shielding were determined and maintained in the calibration effort. Lens combinations for the respective cameras were a 24 mm lens (Mamiya-Sekor 24mm / Fisheye ULD, 1:4 / No.10867) for the FWD camera and a 45 mm lens (Mamiya-Sekor 45mm / 1:2.8 / No.52479) for the AFT camera.

The FWD camera was placed 60 inches from the protective shielding at an angle of 23.4 degrees. The grid board was moved from 64 inches to 100 inches in 4-inch increments. At each increment several frames of film were exposed with a label on the grid board displaying the current distance between the grid board and the camera. The process was repeated for the AFT camera with the grid board being moved from 96 to 140 inches in 4-inch increments.

The first stage in processing the calibration film data was to select a single projector (model/lens/SN) and projection size (15 x 11.125 inches). This projector and projection size had to be maintained while reducing data from the birdstrike films for triangulation results validity. The calibration film for one camera was put into the projector and the image size was adjusted until the 15 by 11.125 inch projection was achieved. Measurements were made from the screen to determine the length of three, 2-inch grid spaces at several different locations and orientations on the image. To facilitate data collection, measurements were made from behind a transparent screen. The calibration data for the FWD and AFT cameras are presented in Tables 16 and 17, respectively.

The magnification factor was computed for each grid location by dividing a known actual length (6 inch) by the measured projected image length from the calibration film. Results from the measurements made at several different locations and orientations on the projection were averaged to determine an effective magnification factor at each camera distance. A least-squares curve fit was used to determine a linear relationship between magnification factor and distance. Calibration curves for the FWD and AFT cameras are presented in Figures 45 and 46, respectively. Note that the raw calibration data were nearly linear. (A linear relationship between magnification factor and distance is assumed in the triangulation program.) The calibration slope and intercept data from the calibration curve fits were used in the triangulation

Table 16. FWD Camera Calibration Data.

Dist. to grid	Raw Data from FWD Camera (cm)						Magnification Factors Based on 6" Actual Dimension						
	Upper Left	Lower Left	Horiz. Center	Vertical Center	Upper Right	Lower Right	Upper Left	Lower Left	Horiz. Center	Vertical Center	Upper Right	Lower Right	Average
64.00	9.20	9.20	9.20	9.30	9.20	9.20	1.6565	1.6565	1.6565	1.6387	1.6565	1.6565	1.6536
68.00	8.70	8.60	8.70	8.80	8.70	8.60	1.7517	1.7721	1.7517	1.7318	1.7517	1.7721	1.7552
72.00	8.20	8.10	8.20	8.10	8.20	8.20	1.8585	1.8815	1.8585	1.8815	1.8585	1.8585	1.8662
76.00	7.70	7.80	7.80	7.80	7.80	7.70	1.9792	1.9538	1.9538	1.9538	1.9538	1.9792	1.9623
80.00	7.30	7.20	7.30	7.30	7.40	7.30	2.0877	2.1167	2.0877	2.0877	2.0595	2.0877	2.0878
84.00	7.00	6.90	7.00	6.90	7.00	6.90	2.1771	2.2087	2.1771	2.2087	2.1771	2.2087	2.1929
88.00	6.60	6.60	6.70	6.60	6.70	6.70	2.3091	2.3091	2.2746	2.3091	2.2746	2.2746	2.2919
92.00	6.40	6.30	6.30	6.40	6.40	6.30	2.3813	2.4190	2.4190	2.3813	2.3813	2.4190	2.4001
96.00	6.00	6.10	6.10	6.00	6.10	6.00	2.5400	2.4984	2.4984	2.5400	2.4984	2.5400	2.5192
100.00	5.70	5.80	5.80	5.80	5.80	5.70	2.6737	2.6276	2.6276	2.6276	2.6276	2.6737	2.6430

Table 17. AFT Camera Calibration Data.

Dist. to grid	Raw Data from FWD Camera (cm)						Magnification Factors Based on 6" Actual Dimension						
	Upper Left	Lower Left	Horiz. Center	Vertical Center	Upper Right	Lower Right	Upper Left	Lower Left	Horiz. Center	Vertical Center	Upper Right	Lower Right	Average
96.00	11.70	11.80	11.60	11.70	11.80	11.70	1.3026	1.2915	1.3138	1.3026	1.2915	1.3026	1.3008
100.00	11.40	11.30	11.10	11.20	11.30	11.20	1.3368	1.3487	1.3730	1.3607	1.3487	1.3607	1.3548
104.00	10.90	10.90	10.80	10.70	10.80	10.80	1.3982	1.3982	1.4111	1.4243	1.4111	1.4111	1.4090
108.00	10.40	10.50	10.30	10.30	10.40	10.40	1.4654	1.4514	1.4796	1.4796	1.4654	1.4654	1.4678
112.00	10.00	10.00	9.90	9.90	10.00	10.00	1.5240	1.5240	1.5394	1.5394	1.5240	1.5240	1.5291
116.00	9.70	9.60	9.50	9.60	9.60	9.60	1.5711	1.5875	1.6042	1.5875	1.5875	1.5875	1.5876
120.00	9.30	9.30	9.20	9.30	9.20	9.30	1.6387	1.6387	1.6565	1.6387	1.6565	1.6387	1.6446
124.00	9.00	9.00	8.90	8.90	9.00	9.00	1.6933	1.6933	1.7124	1.7124	1.6933	1.6933	1.6997
128.00	8.70	8.70	8.60	8.60	8.70	8.70	1.7517	1.7517	1.7721	1.7721	1.7517	1.7517	1.7585
132.00	8.50	8.40	8.40	8.40	8.40	8.40	1.7929	1.8143	1.8143	1.8143	1.8143	1.8143	1.8107
136.00	8.20	8.20	8.10	8.20	8.20	8.20	1.8585	1.8585	1.8815	1.8585	1.8585	1.8585	1.8624
140.00	7.90	7.90	7.90	7.80	7.90	7.90	1.9291	1.9291	1.9291	1.9538	1.9291	1.9291	1.9332

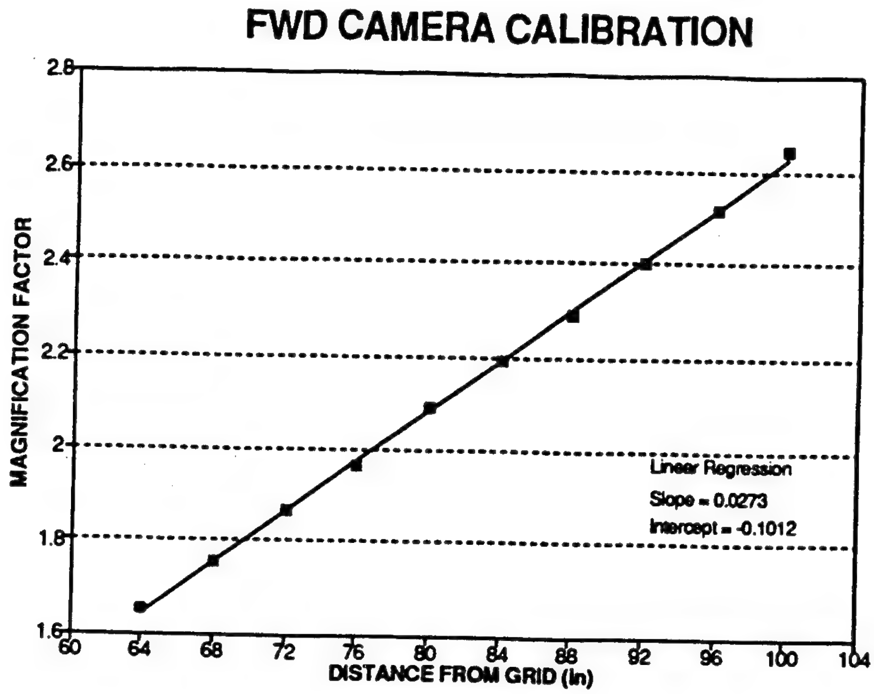


Figure 45. FWD Camera Calibration Curve.

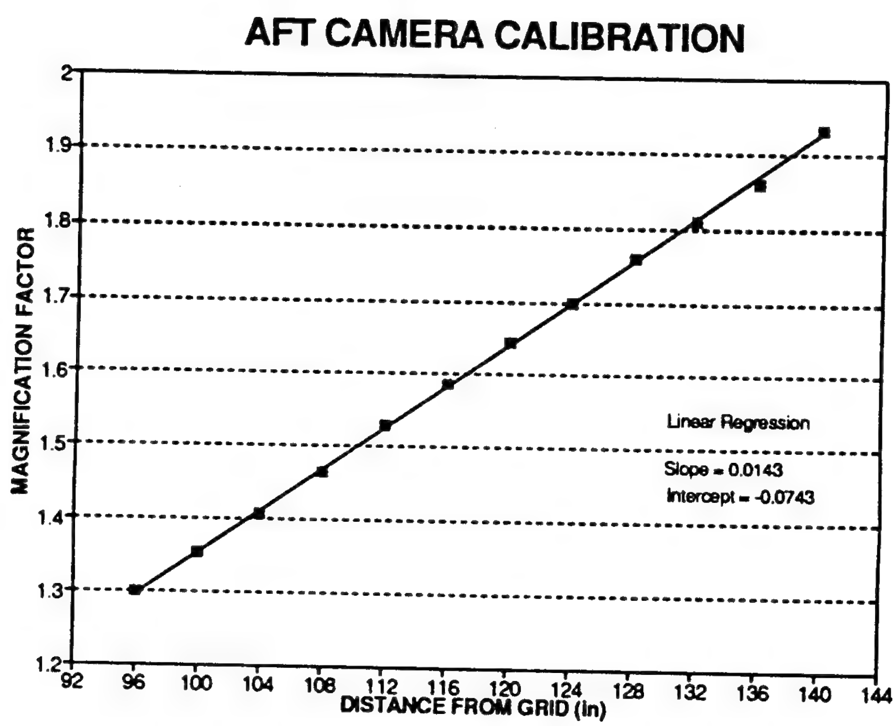


Figure 46. AFT Camera Calibration Curve.

program to define the magnification factor at various camera-to-point distances. The slope and intercept data for the linear fit to magnification factor vs. distance curves are presented below.

Camera	Slope	Intercept
FWD	0.0273	-0.1012
AFT	0.0143	-0.0743

To determine the deflection-time-history response of the polycarbonate panels during the birdstrike, it is necessary to monitor the change in position of various points on the panel. Numerous points were marked on the panel with a known spacing. Each point was marked as a black dot on a white cross. Acrylic paint, which does not degrade the polycarbonate, was used for the white crosses; and a Sanford Sharpie permanent black marker was used for the dots. A template was used to mark the crosses on the camera side of the panel which is opposite of the impacting surface. The panel point spacing, shown in Figure 47, was provided by the Air Force project engineer and was used throughout the test program. A numbering convention was defined to assign each cross with a row and column designation as indicated in the figure. Note that the centerline points are designated with a "-" to facilitate use in the triangulation program. Triangulation data can be collected for any or all of the panel points, but the triangulation program must be rerun for each point.

A coordinate system (triangulation space) was defined at the test site to define the relative positions of the triangulation cameras and the initial location of the points on the panel. This coordinate system (see Figure 44) was oriented such that the Y axis was aligned parallel to the bird path. A laser aimed down the center of the gun barrel was used to locate two points on the floor of the test facility which defined the Y axis. The origin was selected at a point on that line such that all cameras and all points on the panels were aft (+Y) of the origin. The Z axis was defined with the positive direction upward, and the X axis was defined in order to produce a right-handed coordinate system.

Prior to each test the panel was marked using the point template, a pretest photograph was taken, observable flaws were noted, and the panel was mounted into the frame and aligned with

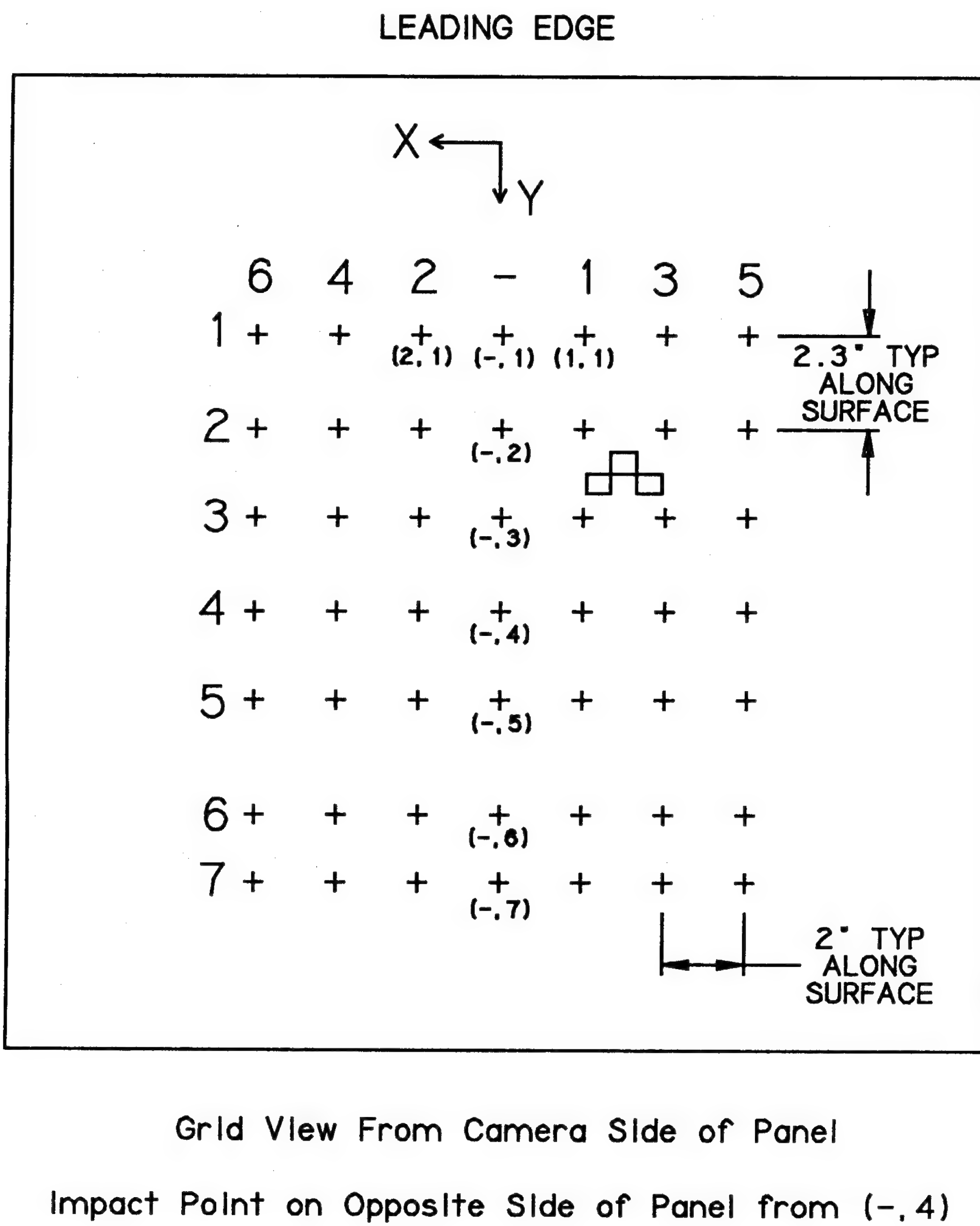


Figure 47. Panel Point Definition.

the laser. Next, the location relative to the coordinate system was measured for each camera reference point and several points on the panel. Initial positions for the remaining points on the panel were computed from the measured point locations and the known spacing of the panel points. All the coordinate system data were recorded for subsequent use in the triangulation program. Once the positions of the cameras and panel points were defined, the bird impact test was performed.

With the test completed, processing of the FWD and AFT films was initiated. The first stage in evaluating the triangulation films was to identify a common event on both films as a starting point for the triangulation analysis. The film frame at or just prior to impact was identified as frame 0. Sequential frames were numbered accordingly over the impact event. The frame numbers were scratched onto the film in the visible portion of the frame so that the frame number was seen during collection of the film data.

Using the same projection size that was used in the calibration effort, the film from one of the cameras was loaded into the projector and advanced to frame 0. The data reduction procedure entailed placing a piece of tracing paper on the projection screen and tracing the initial positions of the panel points of interest. Several objects which remain stationary during the impact event, such as a portion of the support frame, were also traced. Marking these stationary objects was necessary in order to align each frame image properly prior to data collection. As was done with the calibration films, tracing panel points was done from behind a transparent screen to facilitate data collection.

The position of the points at a specific frame number was marked on the tracing paper with a unique symbol. The symbol and the corresponding frame number were recorded on the tracing. This procedure was repeated for each frame of interest during the impact event, and the entire tracing procedure was accomplished for both triangulation cameras.

At the end of the tracing procedure, there was a tracing sheet for each camera which indicated the change in position of the points during the impact event. For each point of interest, data files consisting of azimuth (AZI) and elevation (ELE) data from each triangulation camera

were generated. The positive ELE direction is defined on the tracing sheet as the direction opposite of the bird path. For a rear projection tracing the positive AZI direction is defined such that the resultant of AZI crossed with ELE is in the direction away from the origin of the projected image. The AZI/ELE data were generated using a digitizing tablet to extract the coordinates and to place them in a file. Had the digitizing tablet not been a viable option, the data could have been measured manually from the tracing paper and typed into a file. Typical normalized AZI/ELE data files are presented in Appendix A.

A pulsating timing light signal (common to the all cameras) on the films was used to calculate the frame rate of each camera. The number of frames exposed over 10 timing marks during the birdstrike were counted. Knowing the frequency of the timing signal (1000 timing marks/second), the frame rate (frames/second) was found using the expression:

$$\mathit{Frame\ Rate} = \frac{\mathit{Number\ of\ Film\ Frames}}{\mathit{Number\ of\ Timing\ Signals\ /\ Signal\ Frequency}}$$

For the triangulation algorithm to function properly, both cameras must provide information about the motion of a particular point at the same instant in time. When the frame rates of the two cameras vary significantly, the effects of simultaneity can be lost. The Air Force triangulation program [5] contains modules to normalize the data of the faster camera to the frame rate times of the slower camera. Such normalization efforts were required in this test program.

With the normalized AZI/ELE data files for each camera, the camera frame rates, the calibration films, and the coordinate data for the cameras and panel points, the triangulation code was executed. Appendix A contains an example triangulation session conducted under this program. The triangulation code was executed on an IBM compatible PC which ran GW BASIC. Triangulation output was a single file which indicated the deflection-time-history of a single point during the birdstrike. To evaluate the deflection response of other points on the transparency the triangulation program was rerun. Once the deflection of several points was evaluated, the results were combined to determine the deflected shape of the transparency at various times during the impact event.

4.3 X3D Finite Element Analysis

In support of the birdstrike test program, an impact analysis was performed using the X3D finite element analysis code [6]. Appendix B contains a brief overview of the X3D code and its capabilities. The objective of the impact analysis was to determine analytical deflection-time-history data which could be compared with the triangulation results. The X3D analyses simulated a 2-pound artificial bird impacting a panel at 256 knots and 302 knots. The 30 degree angle between the surface of the panel and the bird path, as well as the impact point, matched the configuration of the actual test program.

The X3D analysis cycle involved several stages. First, the model was defined in PATRAN [7]. The model information was written to a PATRAN neutral file which was a formatted description of the analysis model. The translator program, PATX3D, converted the neutral file into input data for X3D. Additional data, such as material properties and solution control parameters, were manually added to the X3D input file. Once the input file was completed, the X3D analysis was performed. Efforts currently underway with the Analytical Design Package will automate and consolidate the analysis stages required for birdstrike simulation with X3D.

Displacement and stress results from the impact simulation were recorded at regular time intervals in a restart file. The translator program, X3POST, was used to convert the restart file into a format compatible with PATRAN. Finally, results from X3D were input into PATRAN for postprocessing. In addition to the restart file data, X3D generated a "trace" file which contained deflection-time-history data for selected nodes in the model. Pre- and postprocessing were performed on a Sun SPARCstation and X3D was executed on the ASD EASE system.

The PATRAN session files used to generate the impact analysis models are presented in Appendix C. Both two-dimensional (plate/shell) and three-dimensional (hexahedral) models were studied to determine if either modeling technique was beneficial. The resulting X3D models are shown in Figures 48 and 49. The panel shown in Figure 48 was modeled with 1200 plate/shell elements, and the bird was modeled with 960 tetrahedral elements. Because of the difficulty

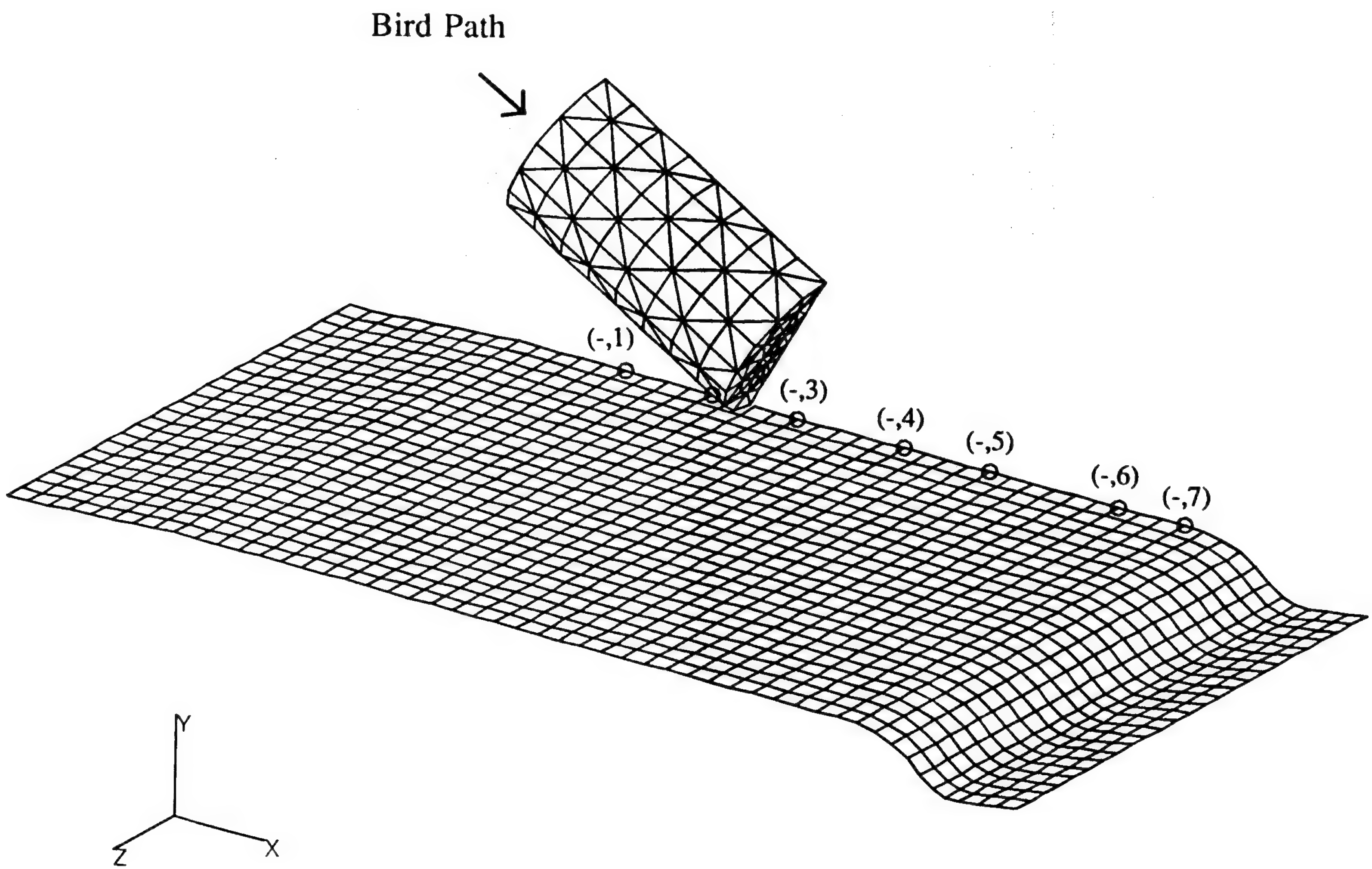


Figure 48. Two-Dimensional X3D Impact Analysis Model.

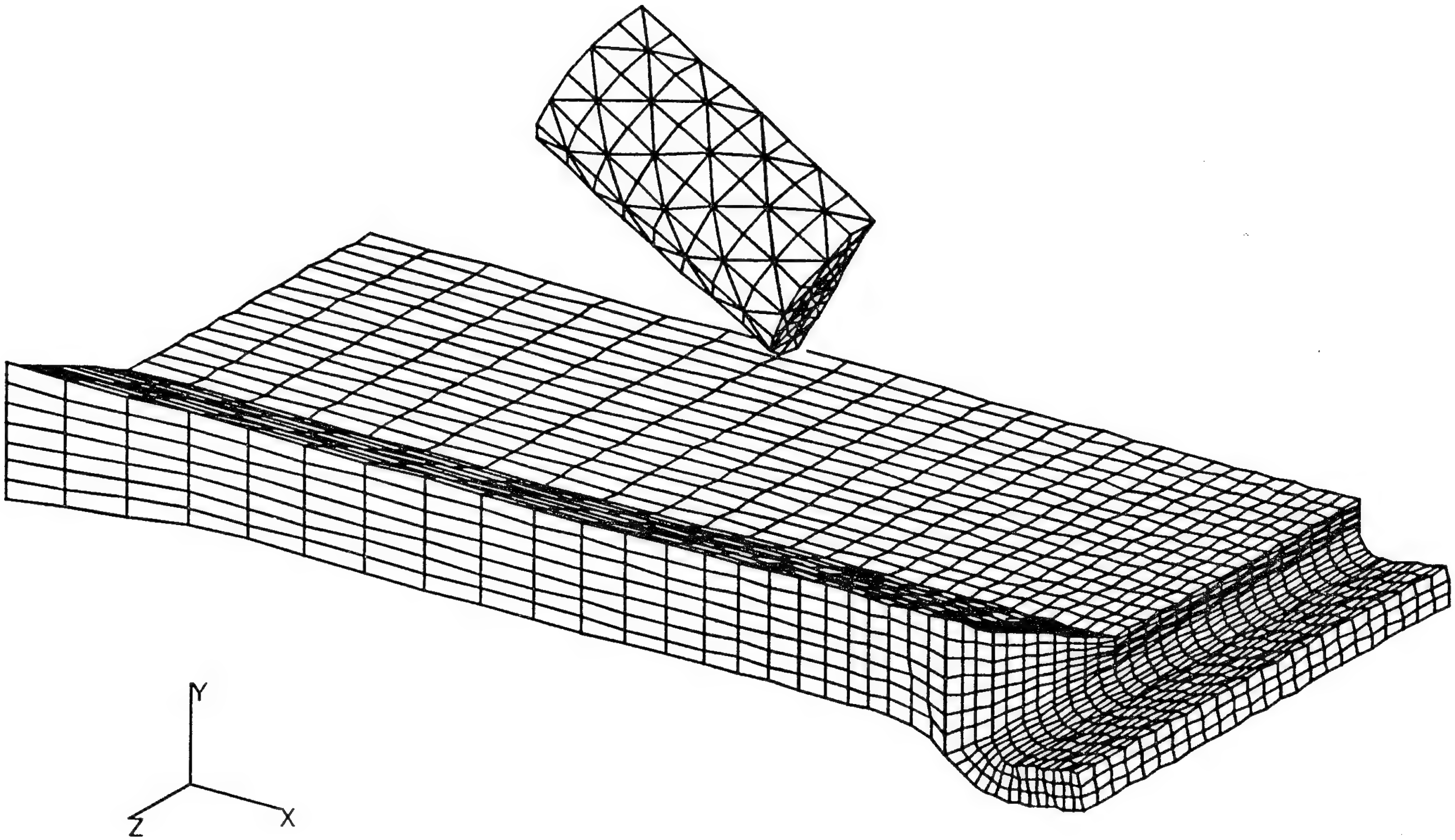


Figure 49. Three-Dimensional X3D Impact Analysis Model.

associated with generating thickness data for the panel within PATRAN, a special purpose computer code was written to generate thickness data for X3D. The panel shown in Figure 49 was modeled with 5376 hexahedral elements and, again, the bird was modeled with 960 tetrahedral elements. Because the panel was modeled as a three-dimensional entity, the thickness of the panel was defined in the actual geometry. In addition to the structural elements, potential contact surfaces were defined for both the panel and bird models. Note that X3D permits modeling of both the target panel and the impacting bird. Algorithms in X3D automatically accounted for the contact conditions between the bird and the panel. Thus, no ad hoc loading condition or estimation of the impact zone was necessary.

Material properties for the artificial bird and the two-dimensional polycarbonate panel were obtained from experimental data from 1991 material testing [8]. (Note that the 1991 properties were used in the analyses because the 1992 testing was not completed when the analyses were performed. Subsequently, it was determined that the 1992 properties were nearly identical to the 1991 properties.) The polycarbonate material was modeled using the following material model parameters [6]:

$E = 300{,}000$ psi	$D = 1.E{+}07$ sec^{-1}
$\upsilon = 0.39$	$p = 14$
$\rho = 0.000111$ lb$_f$-sec^2/in^4	$\sigma_y = 7{,}970$ psi
$H = 7{,}000$ psi	$\sigma_u = 16{,}400$ psi

Note that the polycarbonate material model in X3D was a bilinear stress-strain curve with strain rate dependence and ultimate failure. The artificial bird material was represented by the following material model parameters[6]:

$\rho = 0.0000888$ lb$_f$-sec^2/in^4	$G = 30{,}000$ psi
$K_1 = 337{,}000$ psi	$\sigma_y = 3{,}000$ psi
$K_2 = 729{,}000$ psi	$H = 300$ psi
$K_3 = 2{,}020{,}000$ psi	$\sigma_u = 3{,}000$ psi
$K_t = 1{,}000$ psi	

This represents a pressure-volume response similar to water and a brittle shear behavior. A "high strength" bird model with σ_u = 4,500 psi (approximately 500% plastic strain to failure) was

considered, but the modified bird properties resulted in deflections considerably larger than the 1992 experimental results indicated.

The bird properties for the X3D simulation using the three-dimensional panel model were unchanged from the two-dimensional panel analyses. The polycarbonate properties were obtained from experimental data from polycarbonate panels tested in 1991. (Again note that the 1992 material testing was not completed when the analyses were conducted, but it was subsequently determined that the 1992 properties were nearly identical to those from 1991.) The parameters used for the three-dimensional model were:

$\rho = 0.000111 \text{ lb}_f\text{-sec}^2/\text{in}^4$	$G = 116{,}000$ psi
$K_1 = 415{,}175$ psi	$\sigma_y = 7{,}970$ psi
$K_2 = 2{,}674{,}000$ psi	$H = 7{,}000$ psi
$K_3 = 4{,}202{,}000$ psi	$\sigma_u = 16{,}400$ psi
$K_t = 1{,}000$ psi	

Because all the panels that were evaluated in the test program were centerline impacts, a plane of symmetry was exploited in the X3D analysis. Thus, only one-half of the panel and one-half of the bird were modeled. This resulted in significant run-time savings without affecting the analysis results. Boundary conditions reflecting symmetry were used along the centerline and the panel was assumed to be rigidly constrained along the forward edge/face and along the panel edge/face opposite the centerline.

The X3D solution was performed for 10.0 milliseconds with displacement and stress results being generated every 0.5 milliseconds. The X3D trace option was used to determine the deflection-time-history response of nodes which corresponded to the panel points on the centerline. Thus, trace results can be compared directly to triangulation data to evaluate X3D as an analysis tool.

4.4 Experimental and Analytical Birdstrike Test Results

The results of the birdstrike testing conducted during this program are summarized in Table 18. Injection molding parameters for the individual panels were summarized previously in Table 15. There were 3 panels molded from each of the 4 resins (representing the 4 melt flow indexes) and 2 thicknesses supplying enough panels for 24 tests. Because only 6 of the 1/2-inch panels were tested, only 18 panels were tested in all. Appendix D contains posttest photographs of all panels tested. Each of the tests was performed using a 30 degree impact angle, a panel clamped on three edges (leaving the aft edge unrestrained), and a 2-pound artificial bird for the projectile. The impact velocity was varied throughout the testing in order to determine threshold velocities for the different FTP resins.

Testing prior to 1992 indicated threshold velocities for 1/2-inch thick panels molded from Dow resins were not much greater than 175 knots [8], so this velocity was selected as a starting point for the 1992 testing of the 1/2-inch panels. The experimental resin (XU7-5.5) exhibited a critical velocity between 300 and 400 knots, whereas the 300-15 material exhibited a threshold between 200 and 250 knots. Birdstrike testing of 1992 1/2-inch panels indicated significantly higher impact threshold velocity than previous 1/2-inch panels. Having demonstrated the improved capability of the injection molded panels, efforts were focused on determining the threshold velocity for the 3/4-inch panels, which is the thickness to be used for the CFT.

The impact thresholds of the candidate FTP materials for the 3/4-inch panels are:

Resin	3/4" Panel Impact Threshold (knots)
XU7-5.5	300-350
300-15	250-300
300-6	275-300
300-4	300-325

With improved injection molding resins and processes the 1992 panels exhibited much higher threshold velocities when compared to panels molded prior to 1992. The thresholds of the 1992

Table 18. Birdstrike Test Summary.

Panel	Resin	Thickness (inches)	Planned Velocity (kts)	Actual Velocity (kts)	Pitch (deg)	Yaw (deg)	Up/Down (inches)	Rt/Lt (inches)	Result	Triangulation δ_{max} (inches)
920415-05 MX2054	Dow XU-5.5	1/2	175	174	4 ↓	-	0.75 ↑	0.50 ←	Pass	-
920415-06 MX2054	Dow XU-5.5	1/2	205	206	5.5 ↓	-	0.50 ↑	0.50 →	Pass	-
920415-05 MX2054[2]	Dow XU-5.5	1/2	250	247	5 ↓	-	0.25 ↑	0.25 →	Pass	-
920415-07 MX2054	Dow XU-5.5	1/2	300	301	-	-	0.25 ↑	0.38 →	Pass	-
920415-06 MX2054[2]	Dow XU-5.5	1/2	400	396	3 ↓	11 →	0.50 ↑	0.38 →	Fail**	-
920414-04 MX2053	Dow 300-15	1/2	350	353	4 ↓	-	0.75 ↑	0.25 →	Fail	-
920414-05 MX2053	Dow 300-15	1/2	200	200	8 ↓	-	0.13 ↑	0.25 →	Pass	1.6
920414-08 MX2053	Dow 300-15	1/2	250	249	-	-	0.50 ↑	0.25 ←	Fail**	-
920415-05 MX2050	Dow XU-5.5	3/4	450	450	-	4 →	0.50 ↑	oc*	Fail**	-
920415-06 MX2050	Dow XU-5.5	3/4	350	355	-	-	0.81 ↑	oc	Fail**	-
920415-07 MX2050	Dow XU-5.5	3/4	300	297	4 ↑	-	0.88 ↑	oc	Pass	-
920413-07 MX2049	Dow 300-15	3/4	200	201	-	-	0.38 ↑	oc	Pass	-
920413-09 MX2049	Dow 300-15	3/4	300	302	-	8 →	0.75 ↑	0.25 →	Fail**	-
920413-10 MX2049	Dow 300-15	3/4	250	256	-	2 →	0.75 ↑	0.38 →	Pass	1.0
920414-05 MX2048	Dow 300-6	3/4	300	302	-	-	0.50 ↑	oc	Fail**	1.4
920414-07 MX2048	Dow 300-6	3/4	250	252	2 ↓	3 →	-	0.25 →	Pass	1.2
920414-08 MX2048	Dow 300-6	3/4	275	277	-	-	0.31 ↑	oc	Pass	-
920416-05 MX2047	Dow 300-4	3/4	300	302	3 ↓	-	0.31 ↑	oc	Pass	1.4
920416-07 MX2047	Dow 300-4	3/4	350	357	-	-	0.50 ↑	0.25 ←	Fail	-
920416-08 MX2047	Dow 300-4	3/4	325	327	-	-	0.44 ↑	oc	Fail	-
Tuffak 01		1/2	250	250	-	-	0.50 ↑	oc	Pass	-
Tuffak 02		1/2	350	353	2 ↓	3 ←	0.59 ↑	oc	Pass	-

*On center. **Failure initiated from the clamped region. [2]Second shot on panel.

panels were limited by the test fixture boundary conditions and not the material characteristics (see Appendix D). Results show a slight increase in birdstrike resistance with a decrease in melt flow index for the Dow 300-xx resins, but with such limited test data and test fixture effects, selecting a resin (MFI) based entirely upon impact resistance is not recommended.

Upon completion of the 3/4-inch testing, a 1/2-inch control material, Tuffak, was bird impacted. The 250 and 353 knot impacts on the control material did not result in failure of the polycarbonate sheet. It was determined, though, that due to the change in clamping conditions necessary to accommodate the Tuffak panels, it would be difficult to correlate the test results with those of the injection molded panels. For this reason the Tuffak tests were not used to any further extent.

The Air Force project engineer in conjunction with UDRI selected four, 3/4-inch thick panels for triangulation analysis; three panels that passed the birdstrike test, and one panel that failed. The panel that failed (920414-05 MX2048, Dow 300-6) was analyzed to determine if the deflection-time history response prior to failure was similar to that of panels which passed the birdstrike test. As indicated in Figure 50, it was determined that no significant differences existed between the panel responses up to the point of maximum deflection at which the panel failed. Maximum deflections from the triangulation analyses were presented in Table 18.

Triangulation results from numerous points on a transparency can be combined to determine the deflected shape as a function of time during the bird impact event. This information can be used to determine the relative position between the transparency, bird, and objects inside the cockpit, such as the pilot's head and the head-up display system. Figure 51 shows the deflected shape of panel 920413-10 MX2049 along the centerline at several stages during the birdstrike. The left-most point at each time represents the clamped leading edge of the panel. Figure 51 shows the deformation pocket had begun to form prior to 1.55 milliseconds, had traveled to the aft edge by 3.11 milliseconds, and had begun rebounding by 3.88 milliseconds.

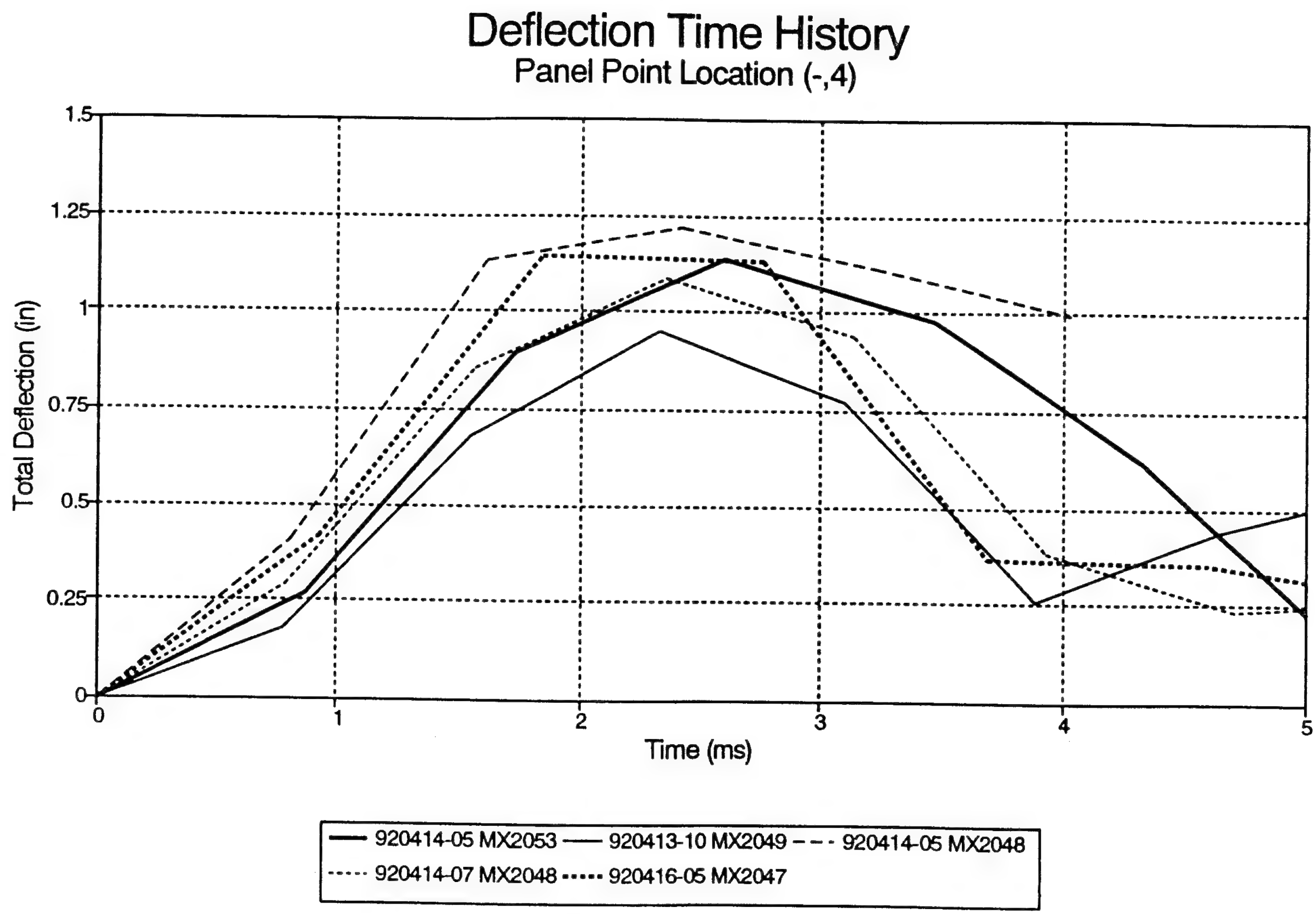


Figure 50. Triangulation Results at Panel Point Location (-,4).

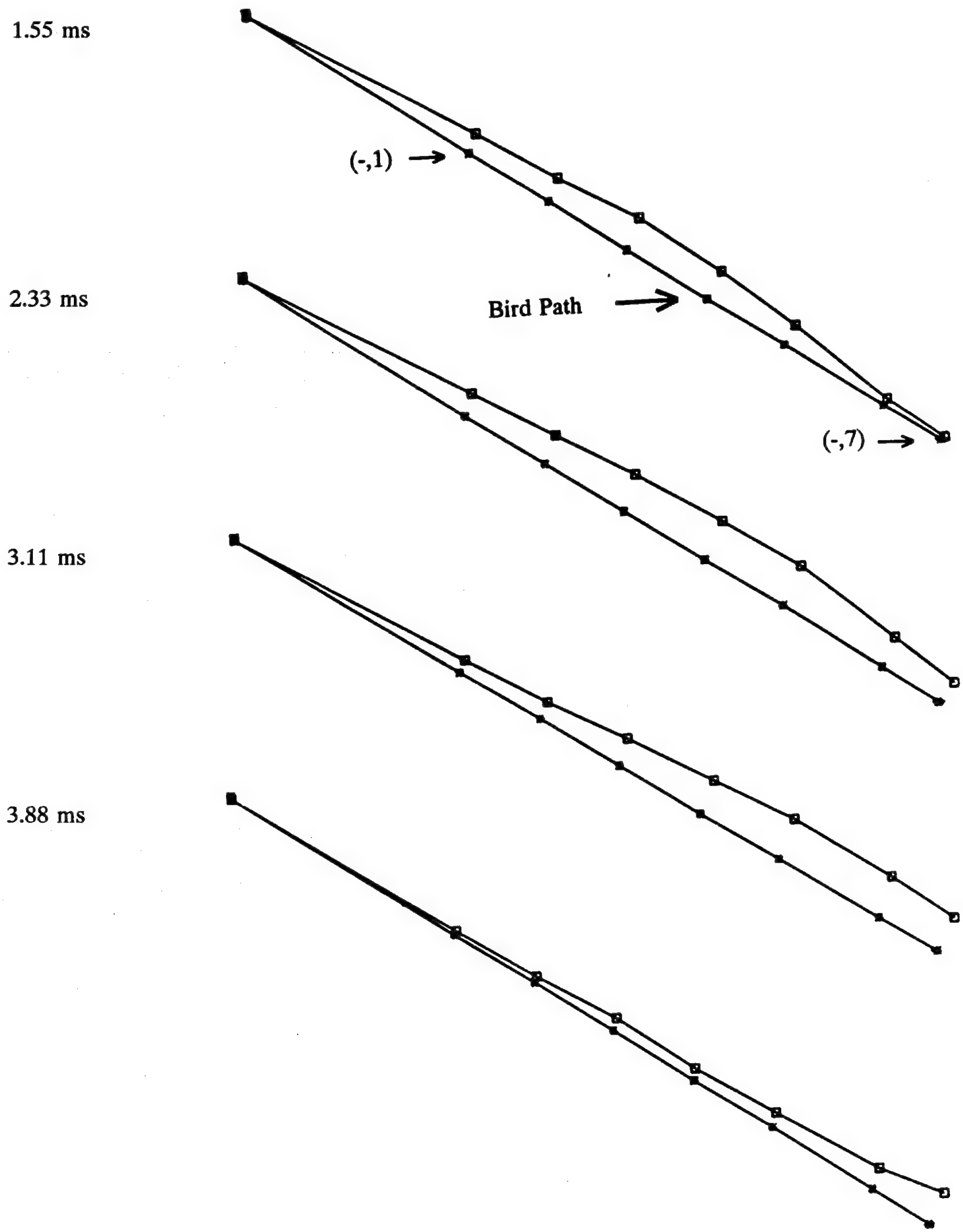


Figure 51. Centerline Deflection Response of Panel 920413-10 MX2049.

In support of the birdstrike test program, impact analyses were performed using the X3D finite element analysis software. X3D and the polycarbonate panel impact model were discussed in Section 4.3. The X3D analyses simulated 2-pound artificial birds impacting a panel at 256 and 302 knots. The 30 degree impact angle, impact point, and boundary conditions were defined in accordance with the test program. Properties for polycarbonate and bird materials as defined in Section 4.3 were used throughout the analysis.

Figures 52-55 show deformed geometry plots at one millisecond intervals (from 1 to 4 milliseconds) during the X3D impact simulation for the two-dimensional model. Figures 56-59 show similar plots for the three-dimensional model. Note that the "low strength" bird model used in the X3D analysis resulted in a large number of bird element failures.

Figures 60-73 compare X3D results with triangulation results from impact tests on panels 920413-10 MX2049, 920414-07 MX2048, and 920416-05 MX2047 at panel point locations (-,1) to (-,7) along the panel centerline. Figures 60-66 show results for the 256 knot X3D analysis compared to the 256 knot test data on panel 920413-10 MX2049 and the 252 knot test data on panel 920414-07 MX2048. Figures 67-73 show results for the 302 knot comparison of panel 920416-05 MX2047. The X3D impacts showed good agreement with the experimental impacts for points (-,1) to (-,4) from initial impact to the point of return to the preimpact position. However, the X3D solution and the triangulation results diverge during rebound (after approximately 4 milliseconds). Agreement between points (-,5) to (-,7) is obtained up to the point of maximum deflection, at which point the solution diverges. Potential reasons for the solution divergence include different boundary conditions between the testing and analysis and differences between the material model and actual material behavior.

It is important to note that both the two- and three-dimensional finite element models resulted in similar deflections. The three-dimensional model is generally less flexible due to the element formulation. It is anticipated that with a mesh refinement through the panel thickness, the three-dimensional solution would approach the two-dimensional panel results. It is recommended, however, that two-dimensional models be used for the panel impact simulations

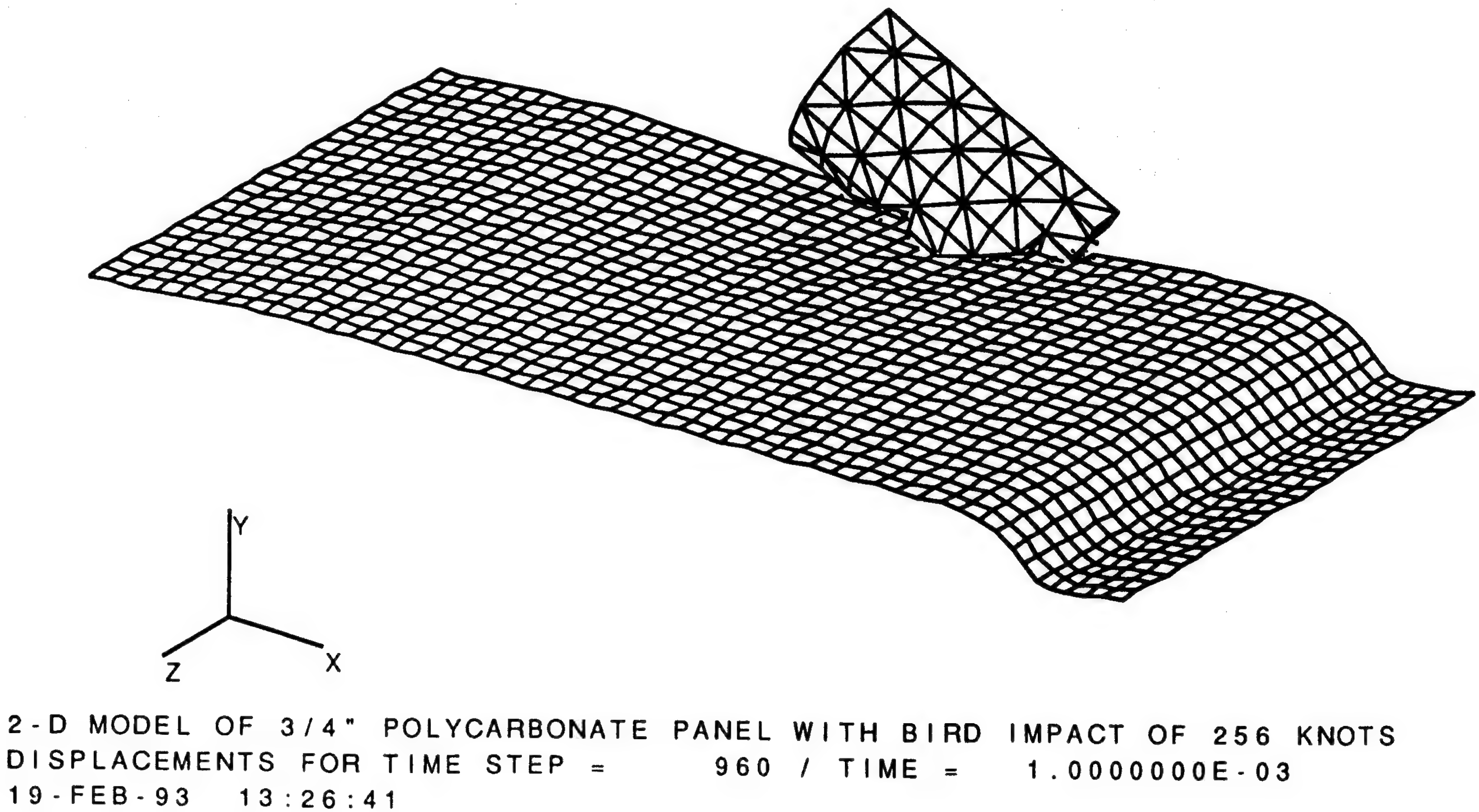


Figure 52. Two-Dimensional X3D Deformed Geometry Plot at 1 millisecond.

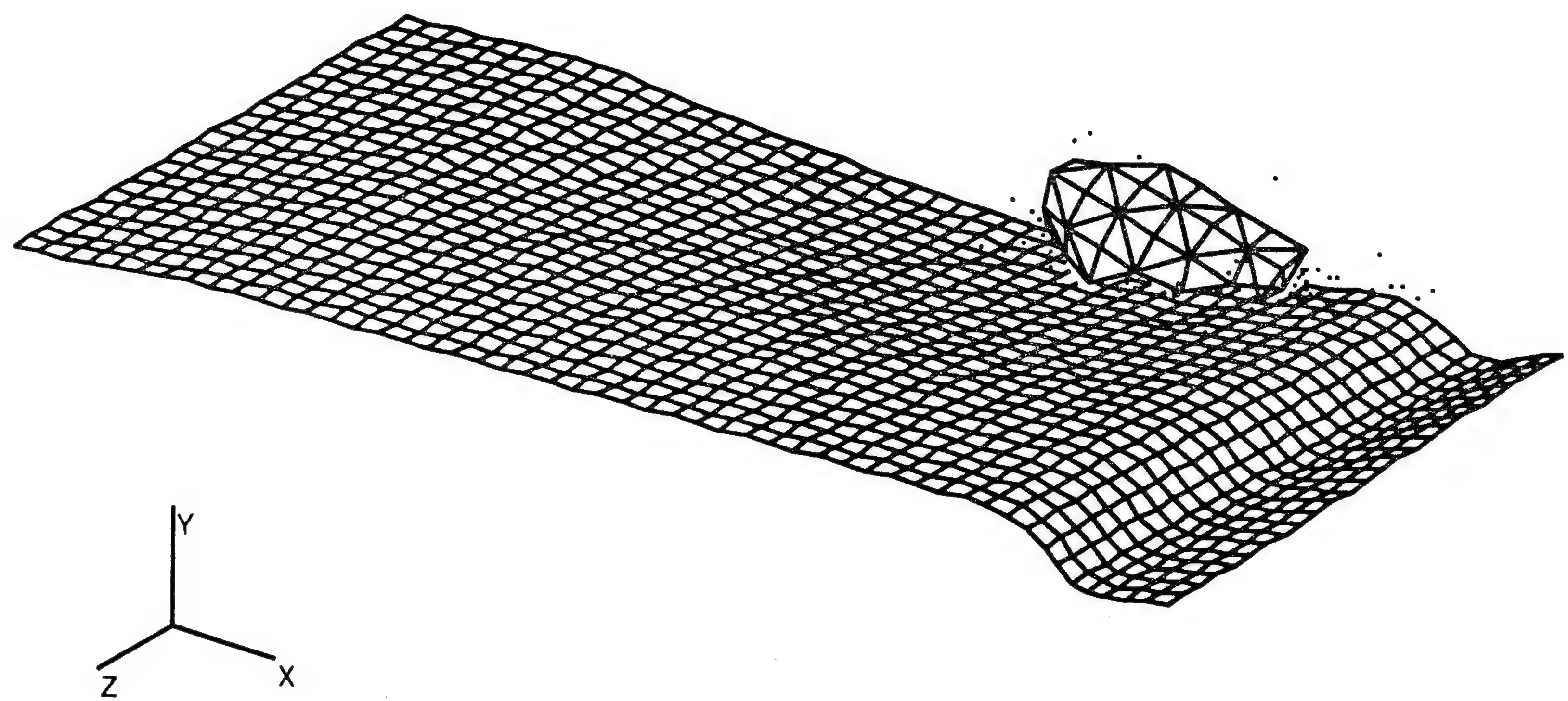


Figure 53. Two-Dimensional X3D Deformed Geometry Plot at 2 milliseconds.

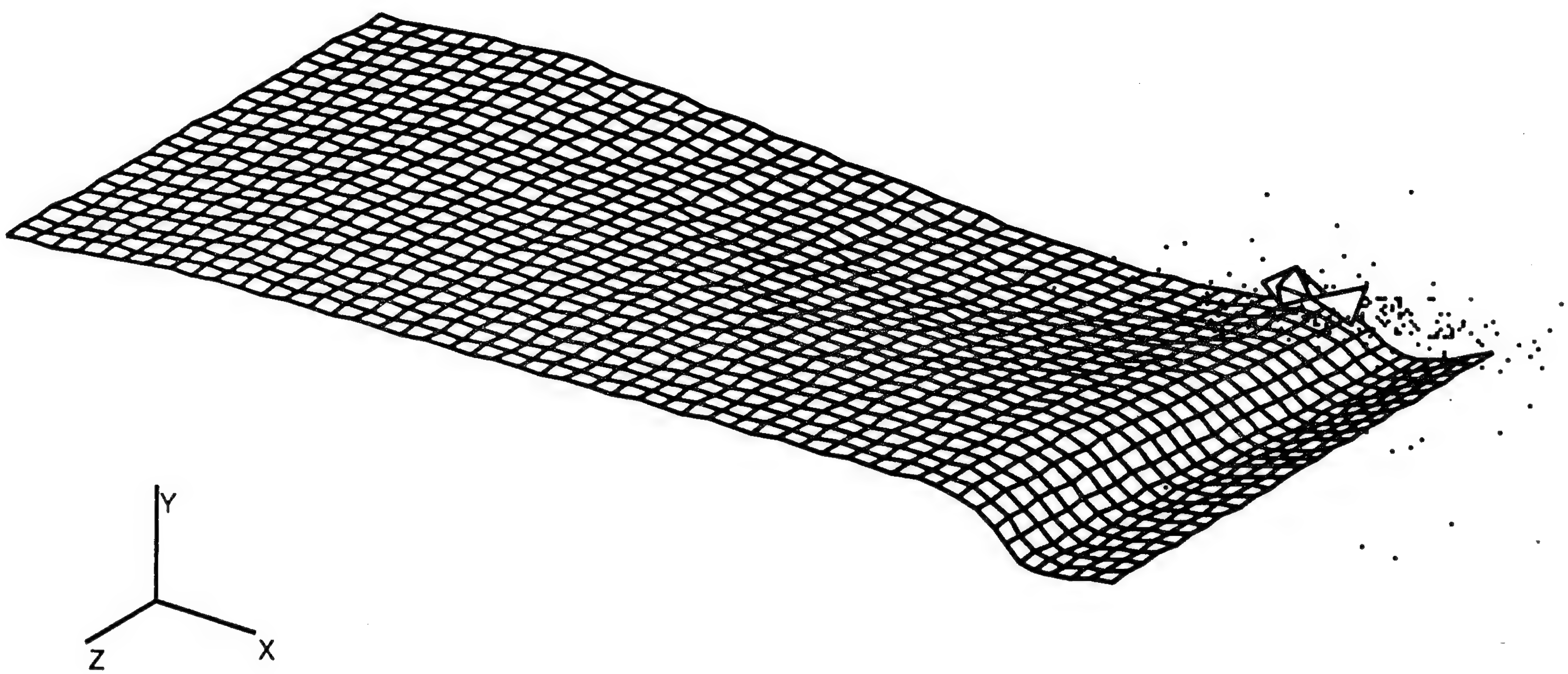


Figure 54. Two-Dimensional X3D Deformed Geometry Plot at 3 milliseconds.

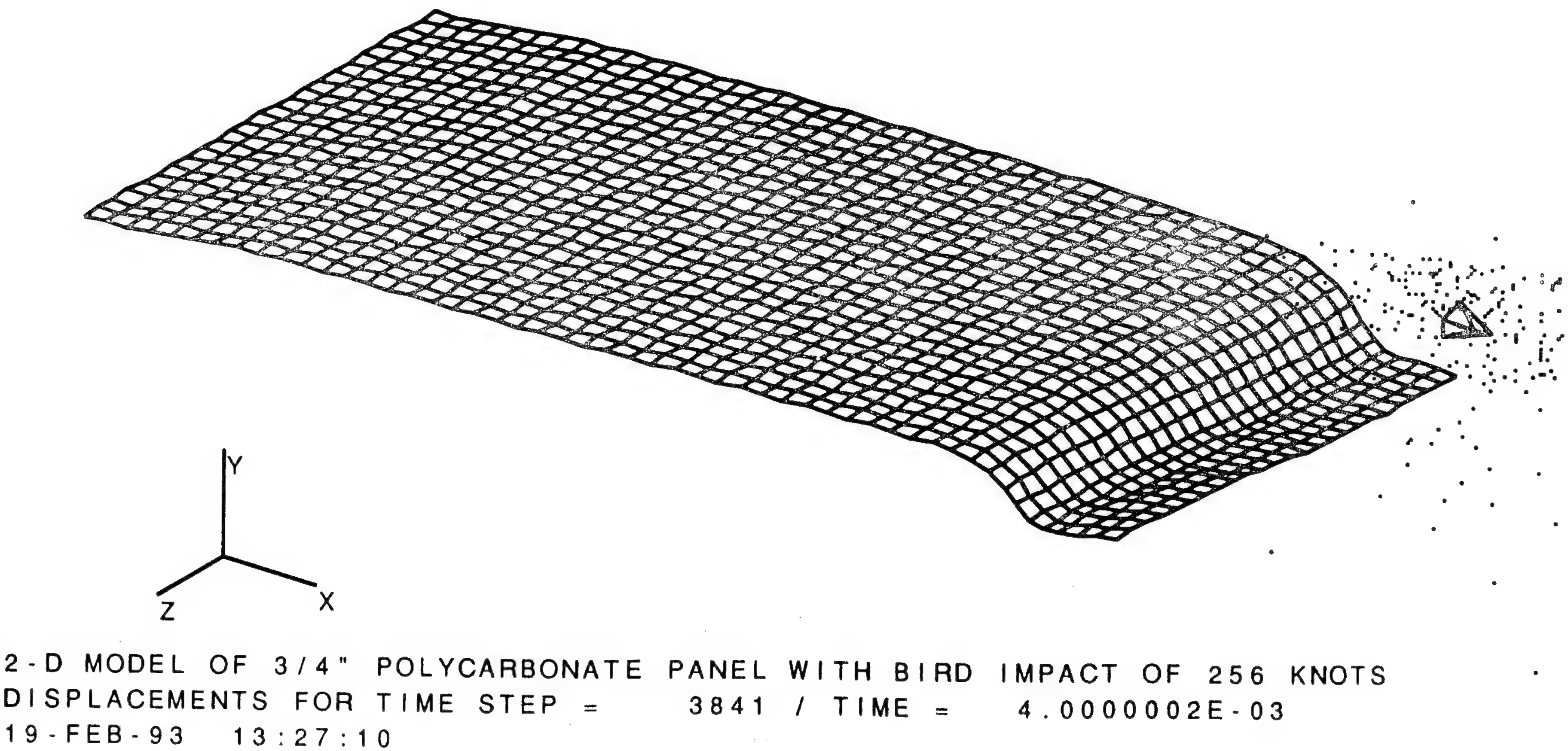


Figure 55. Two-Dimensional X3D Deformed Geometry Plot at 4 milliseconds.

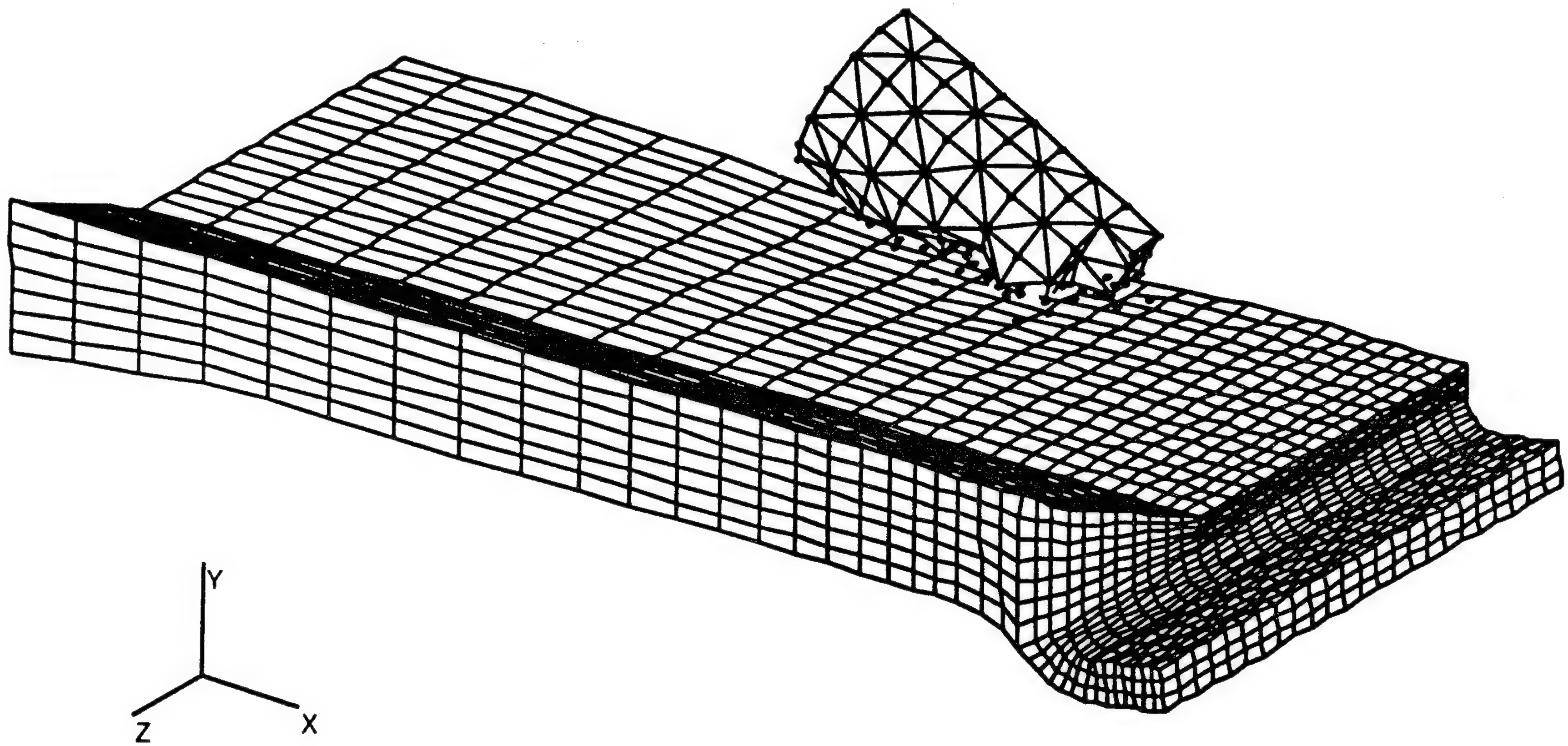


Figure 56. Three-Dimensional X3D Deformed Geometry Plot at 1 millisecond.

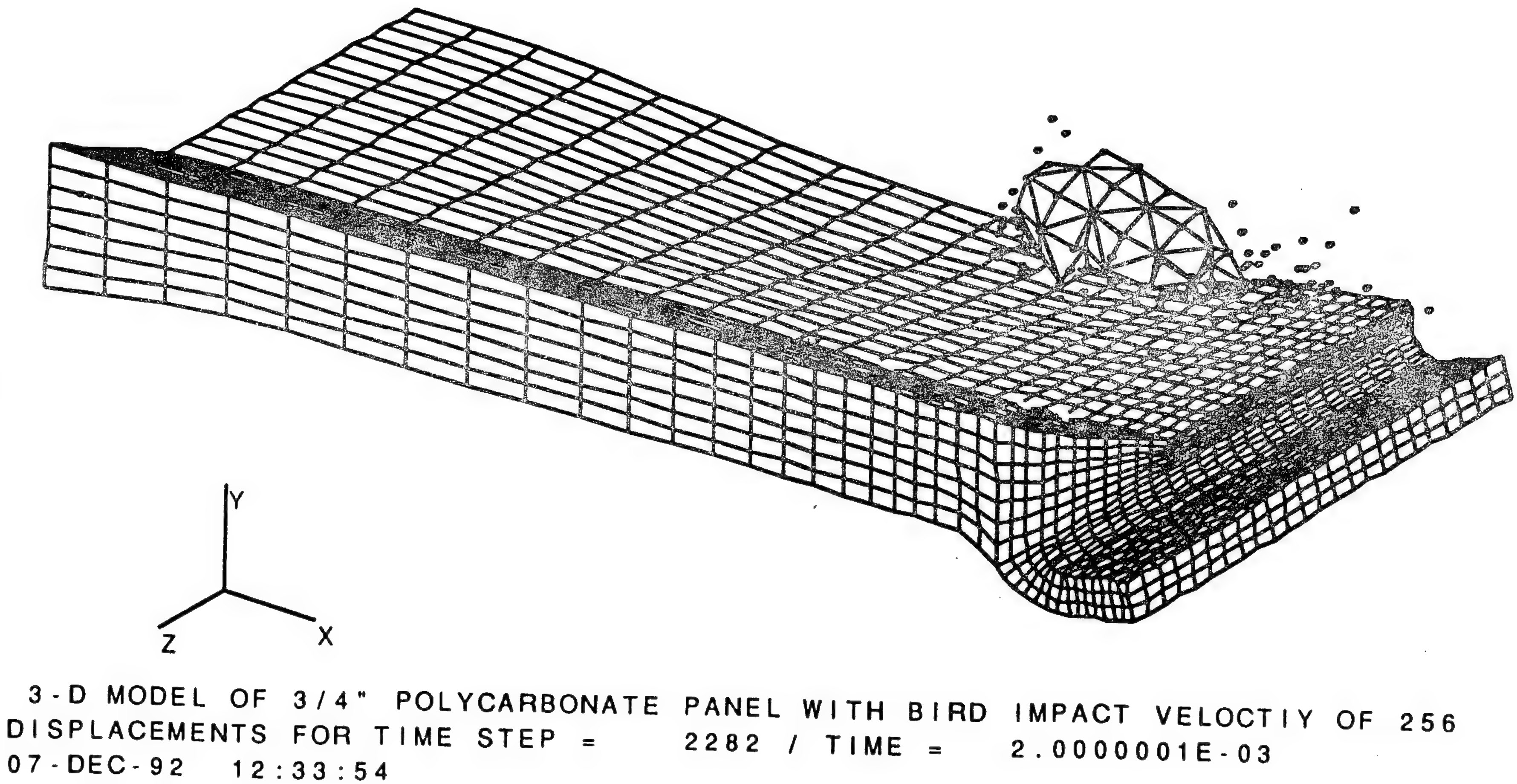


Figure 57. Three-Dimensional X3D Deformed Geometry Plot at 2 milliseconds.

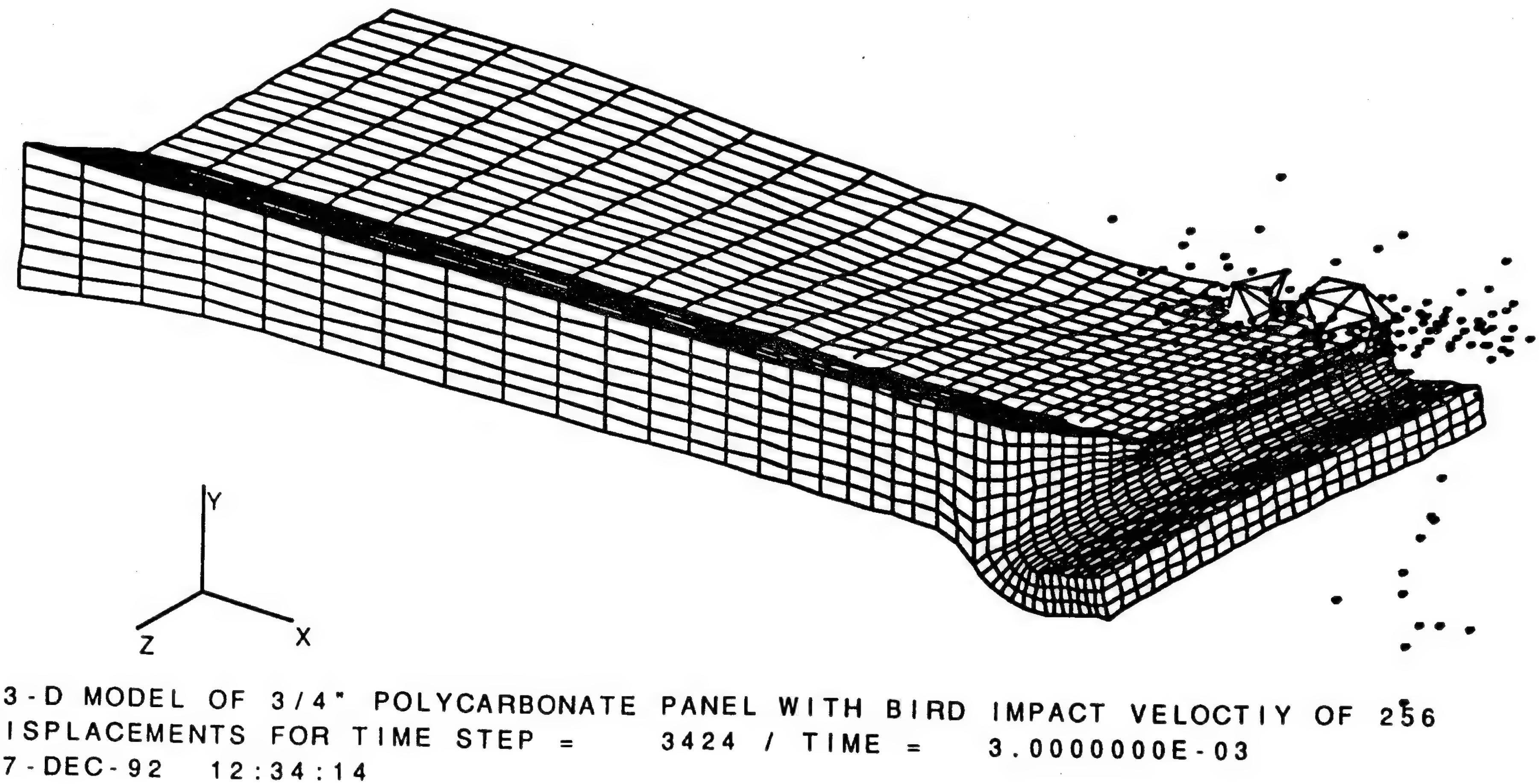


Figure 58. Three-Dimensional X3D Deformed Geometry Plot at 3 milliseconds.

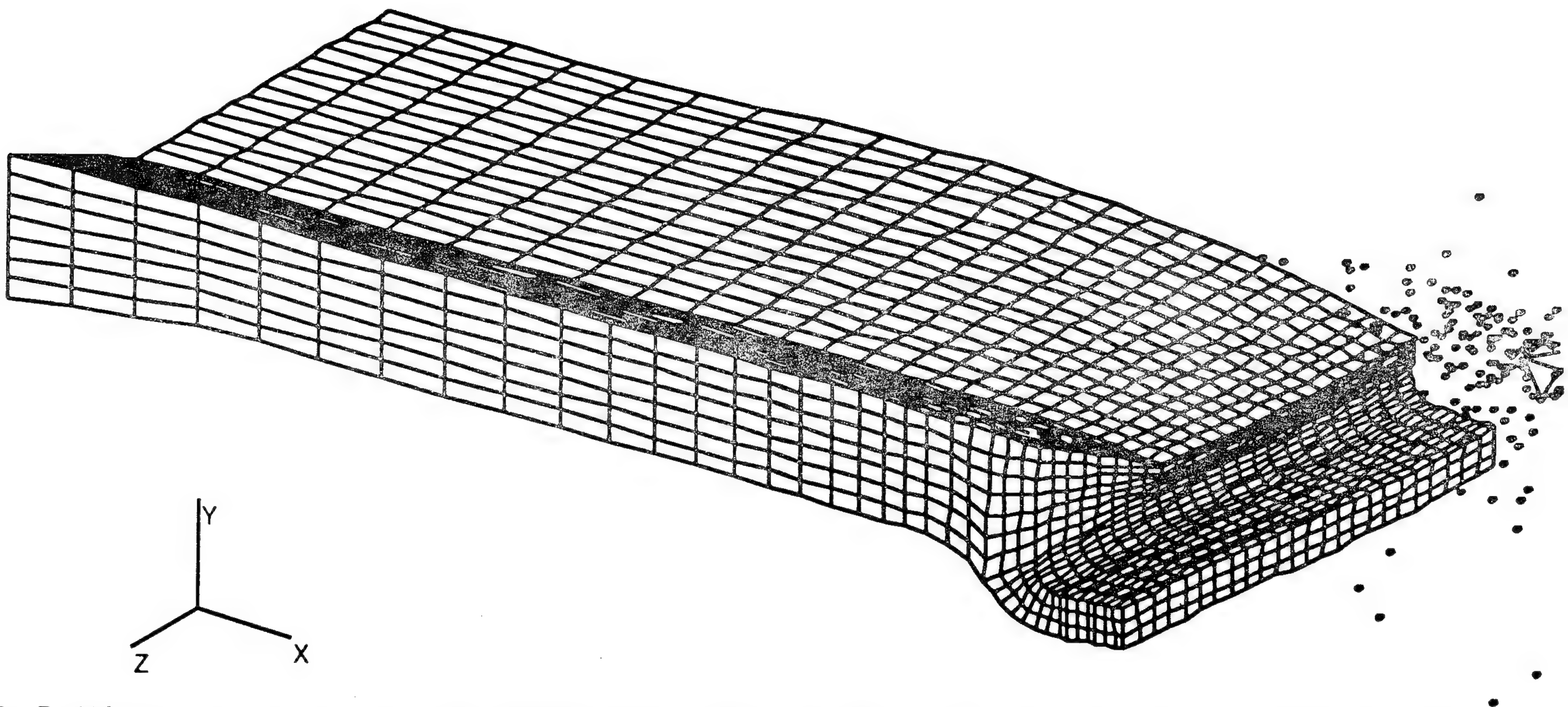


Figure 59. Three-Dimensional X3D Deformed Geometry Plot at 4 milliseconds.

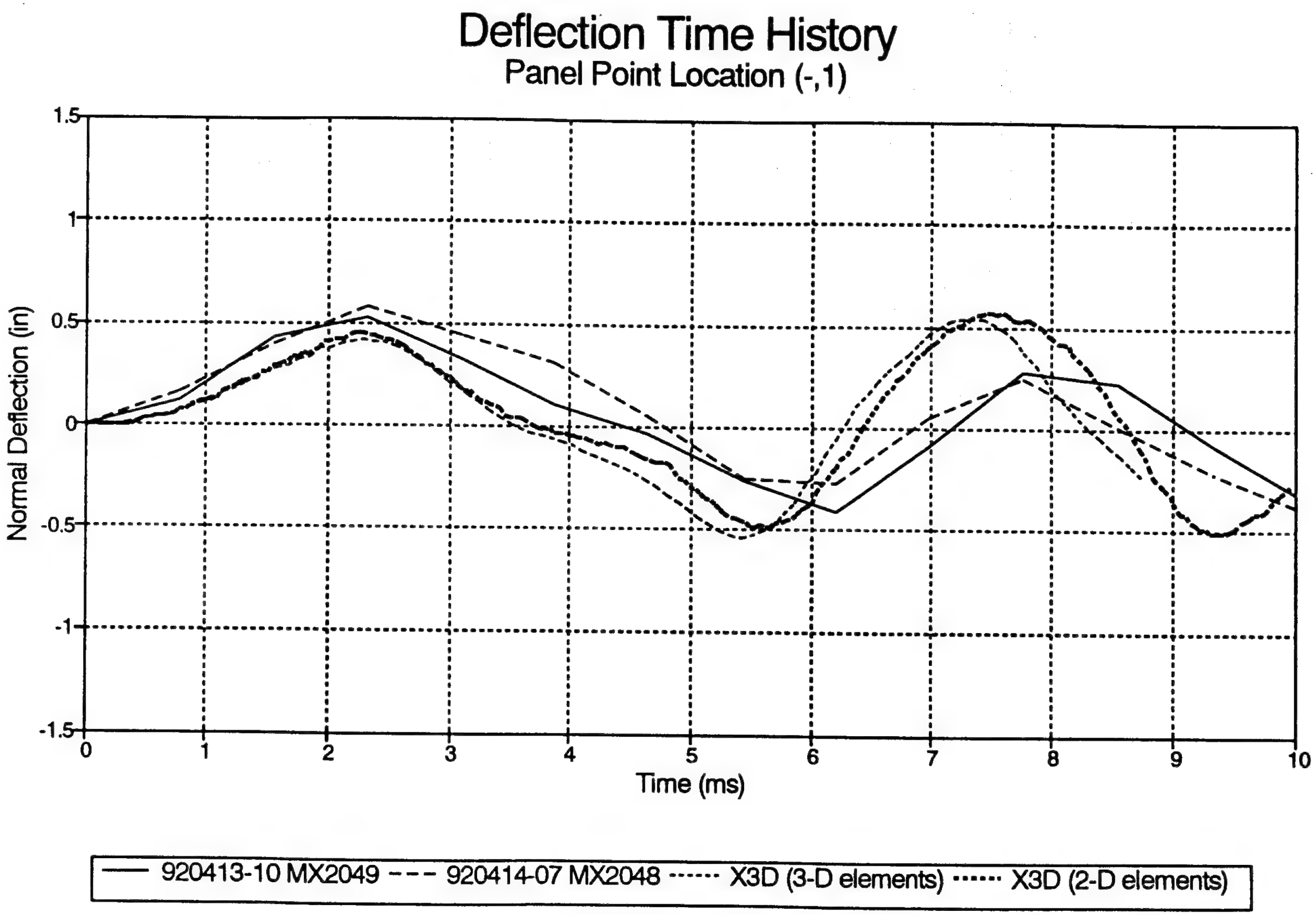


Figure 60. Triangulation/X3D Results Comparison at Panel Point Location (-,1).

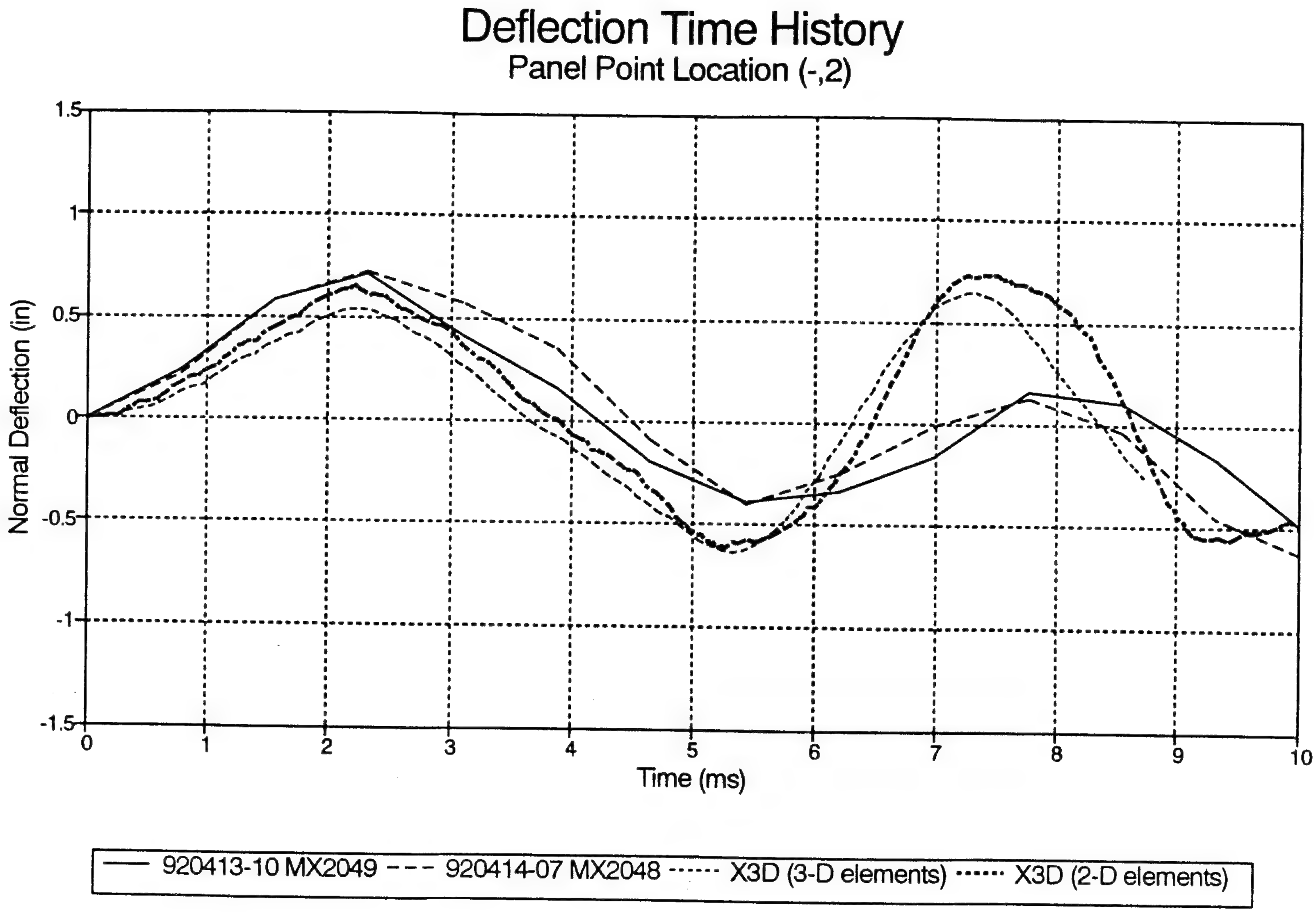


Figure 61. Triangulation/X3D Results Comparison at Panel Point Location (-,2).

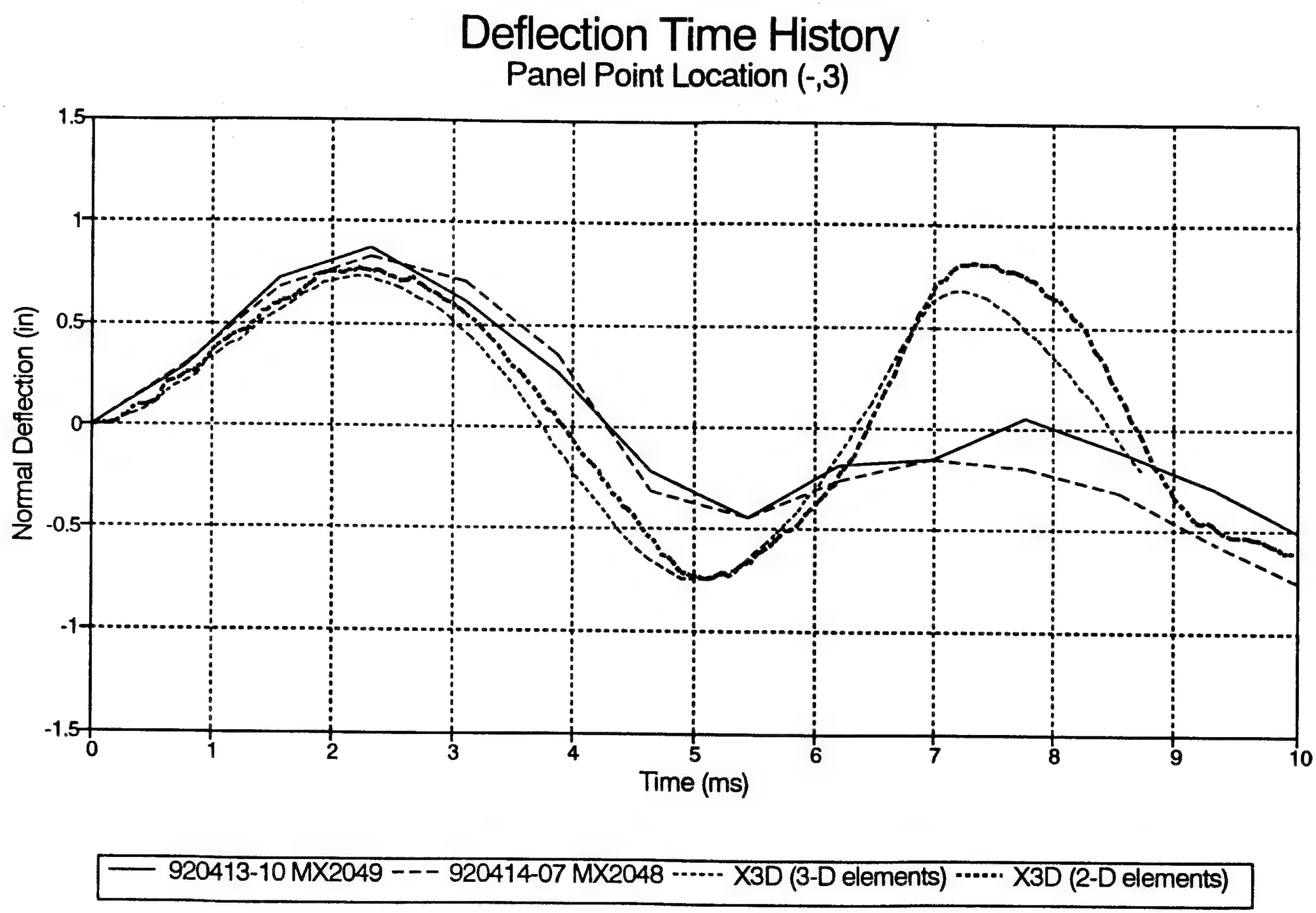


Figure 62. Triangulation/X3D Results Comparison at Panel Point Location (-,3).

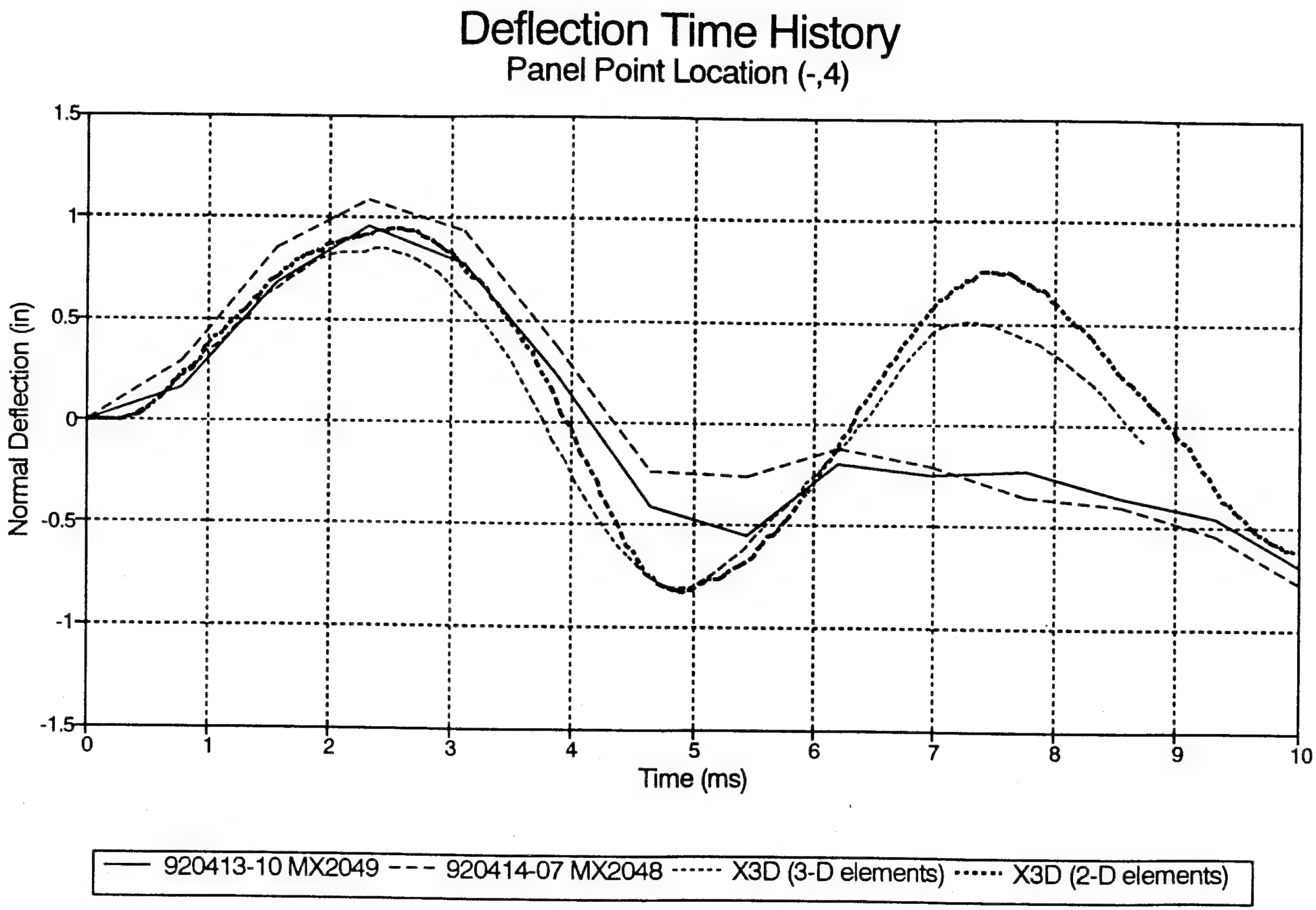


Figure 63. Triangulation/X3D Results Comparison at Panel Point Location (-,4).

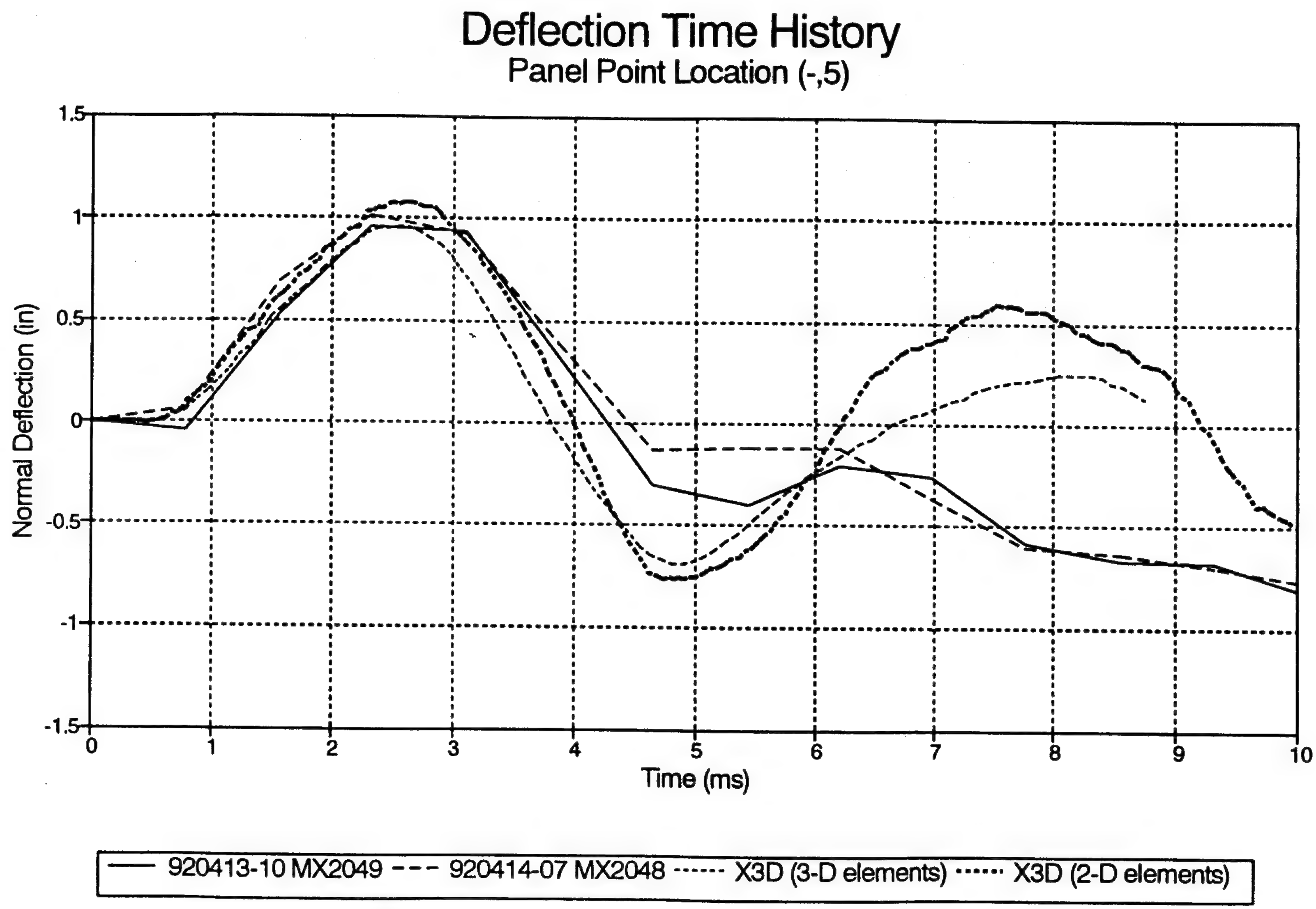


Figure 64. Triangulation/X3D Results Comparison at Panel Point Location (-,5).

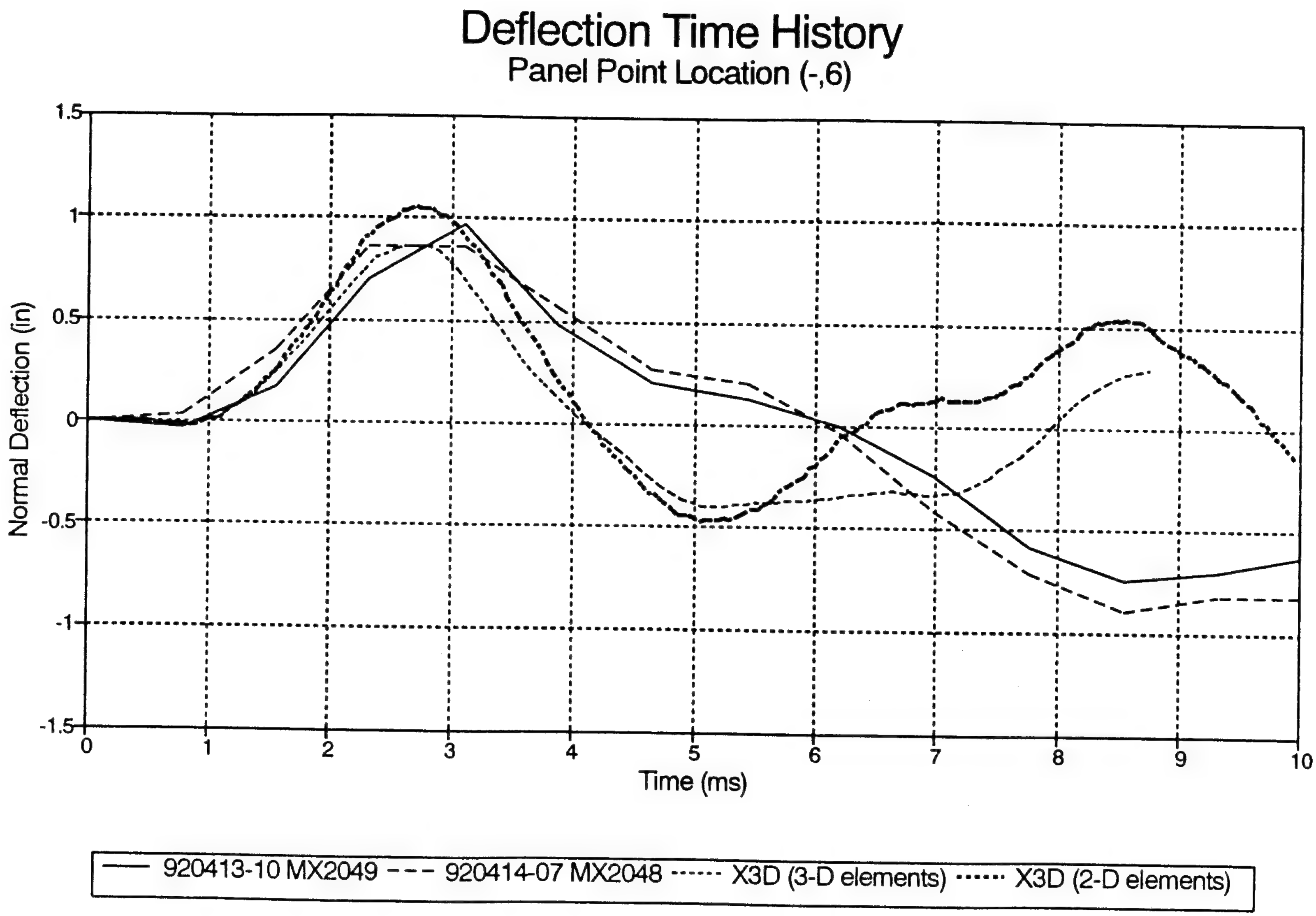


Figure 65. Triangulation/X3D Results Comparison at Panel Point Location (-,6).

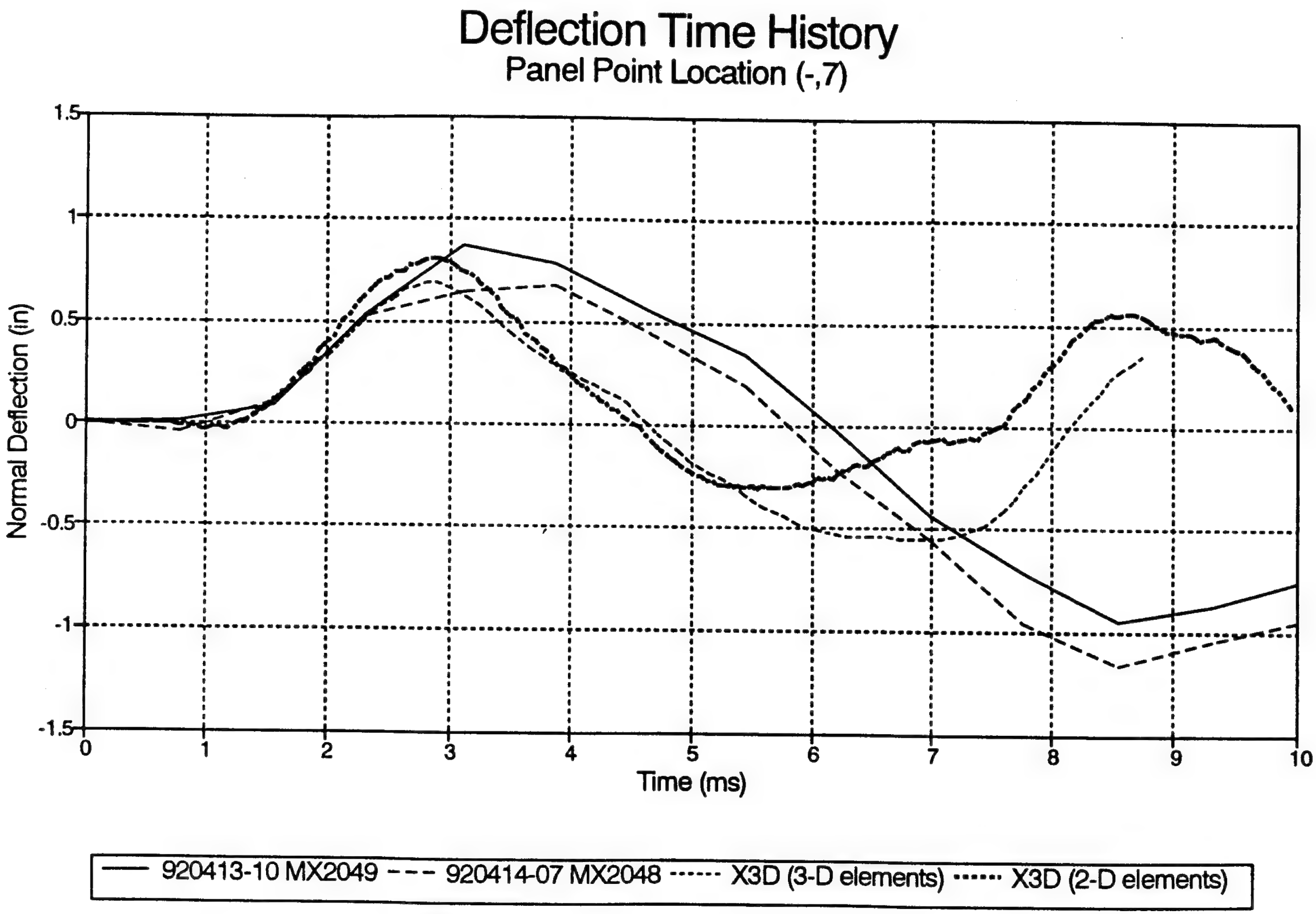


Figure 66. Triangulation/X3D Results Comparison at Panel Point Location (-,7).

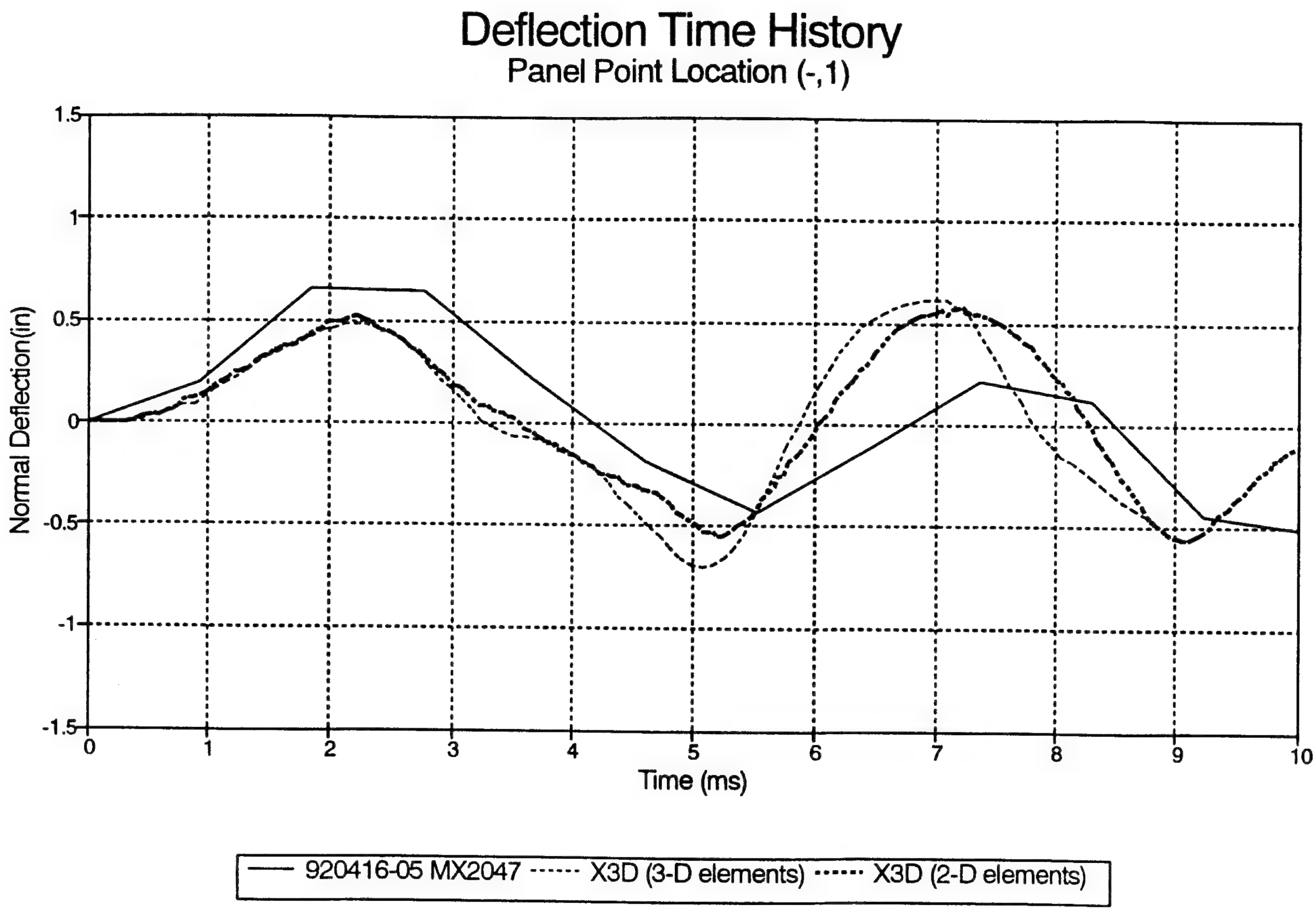


Figure 67. Triangulation/X3D Results Comparison at Panel Point Location (-,1).

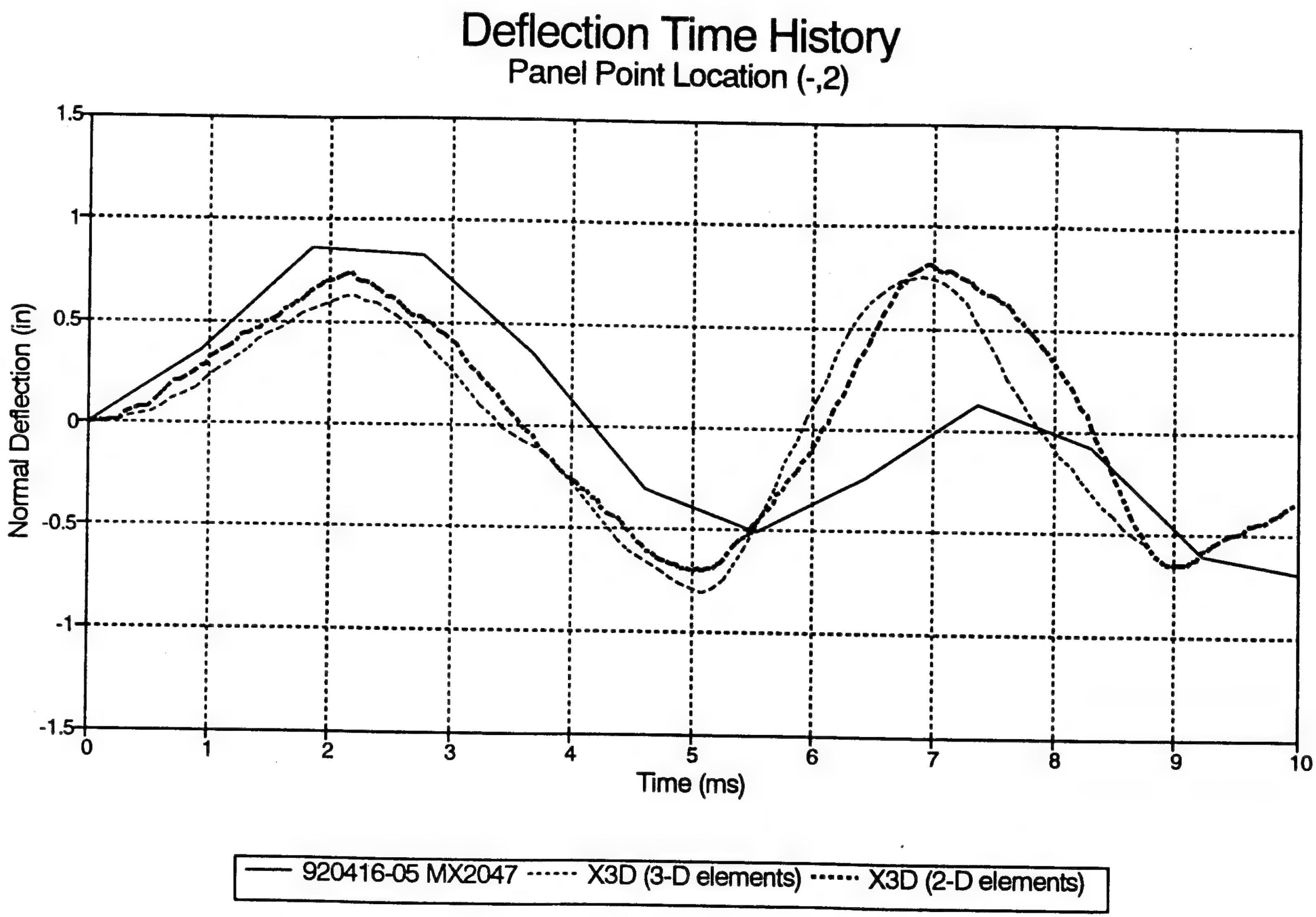


Figure 68. Triangulation/X3D Results Comparison at Panel Point Location (-,2).

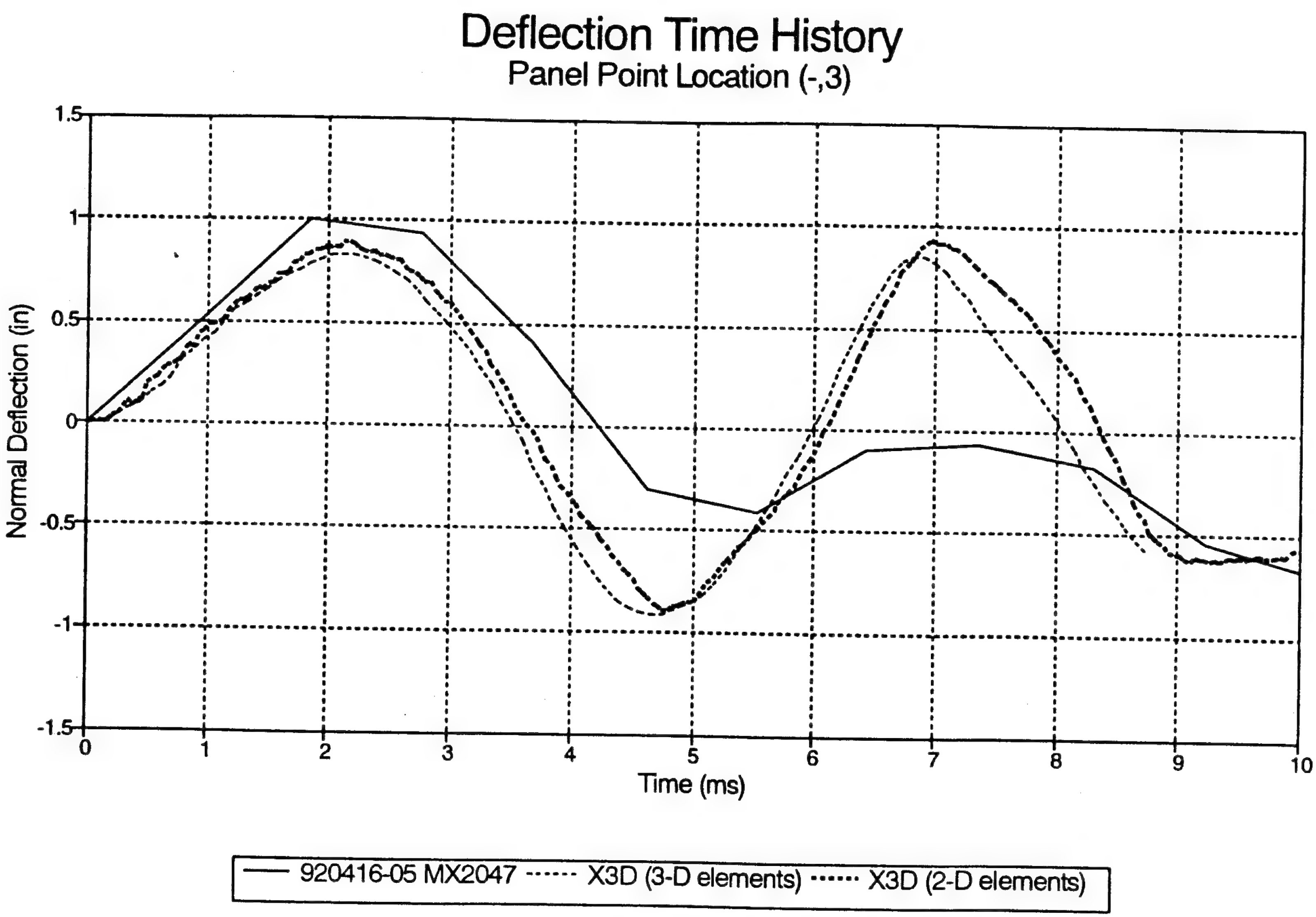


Figure 69. Triangulation/X3D Results Comparison at Panel Point Location (-,3).

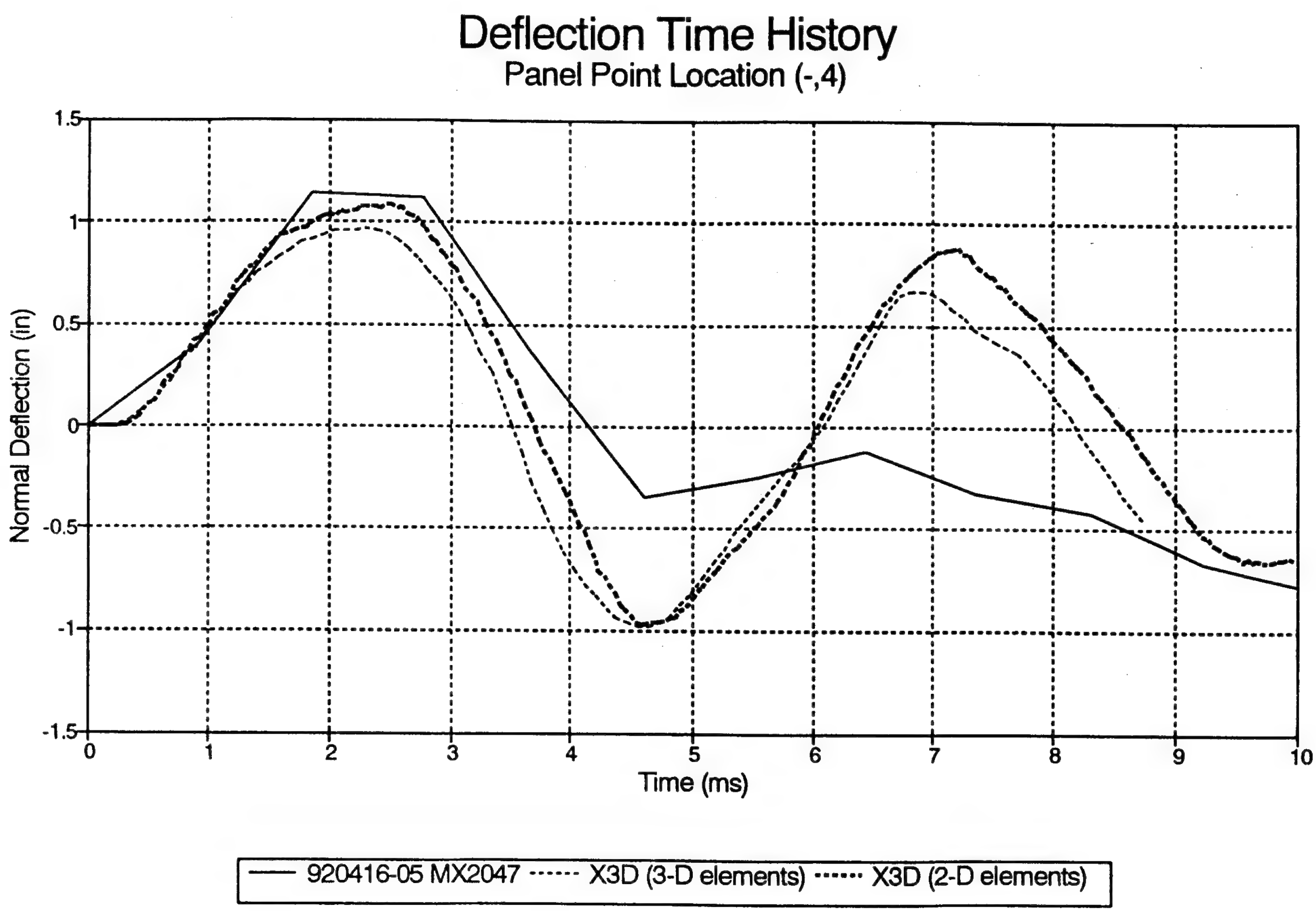


Figure 70. Triangulation/X3D Results Comparison at Panel Point Location (-,4).

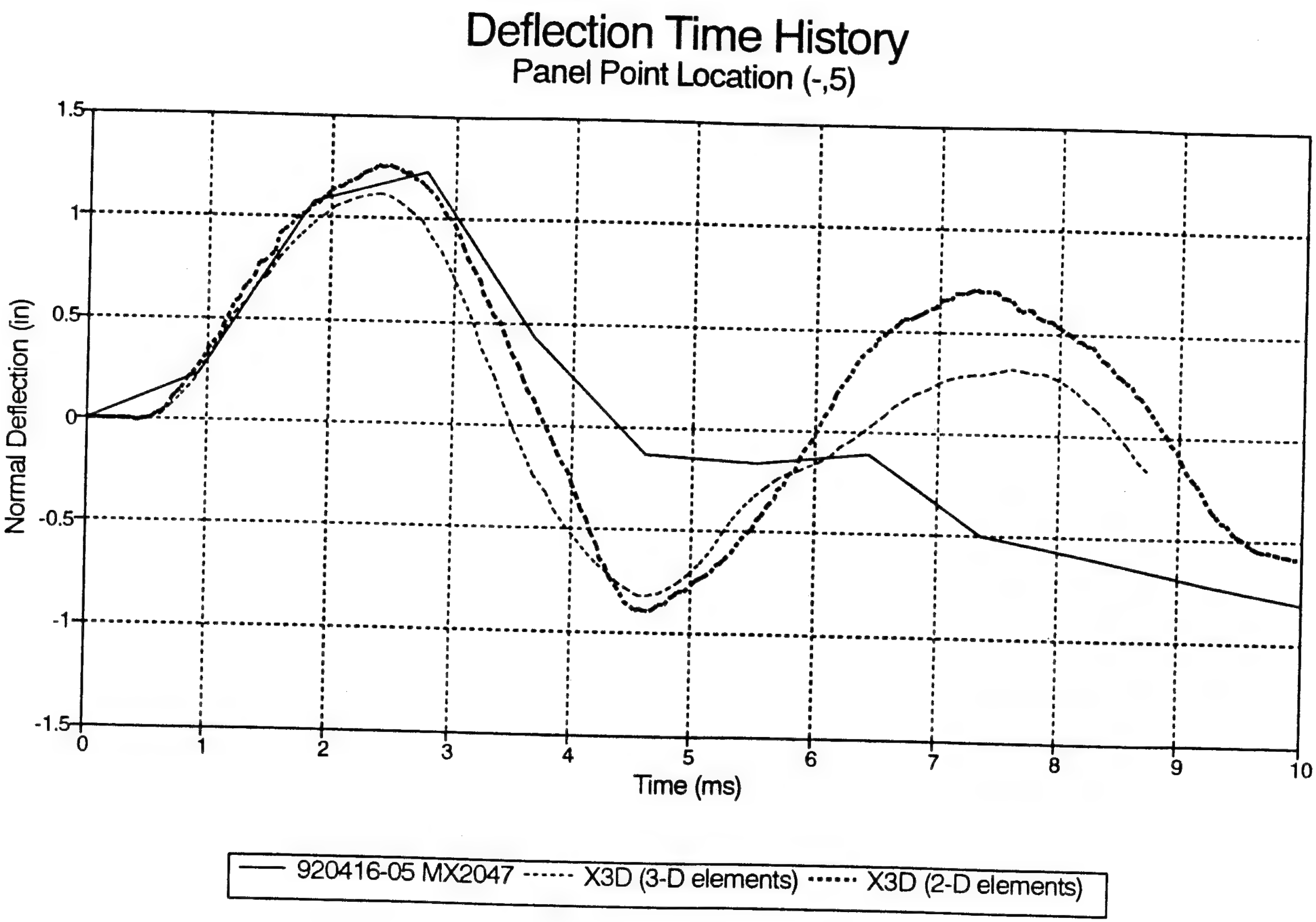


Figure 71. Triangulation/X3D Results Comparison at Panel Point Location (-,5).

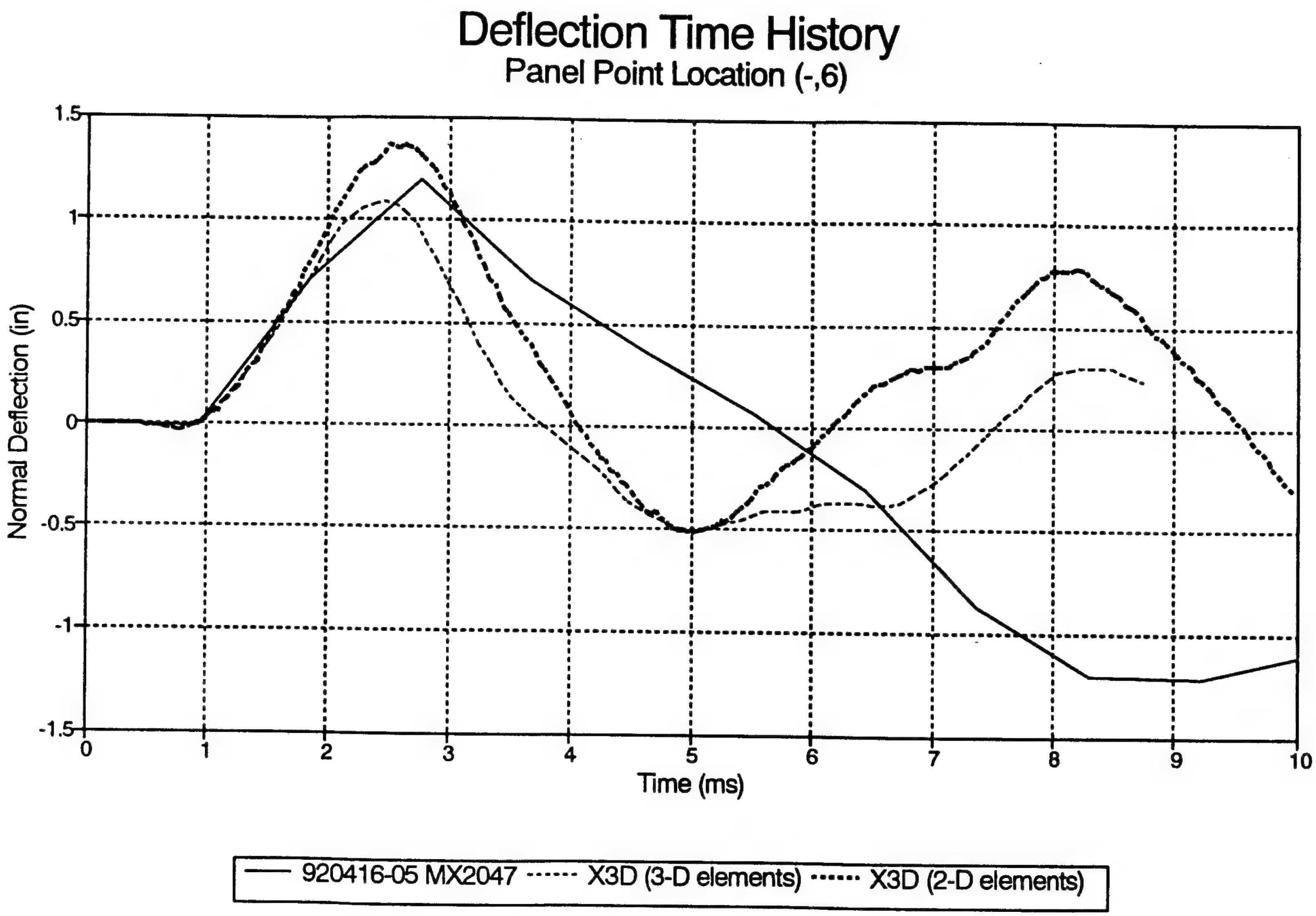


Figure 72. Triangulation/X3D Results Comparison at Panel Point Location (-,6).

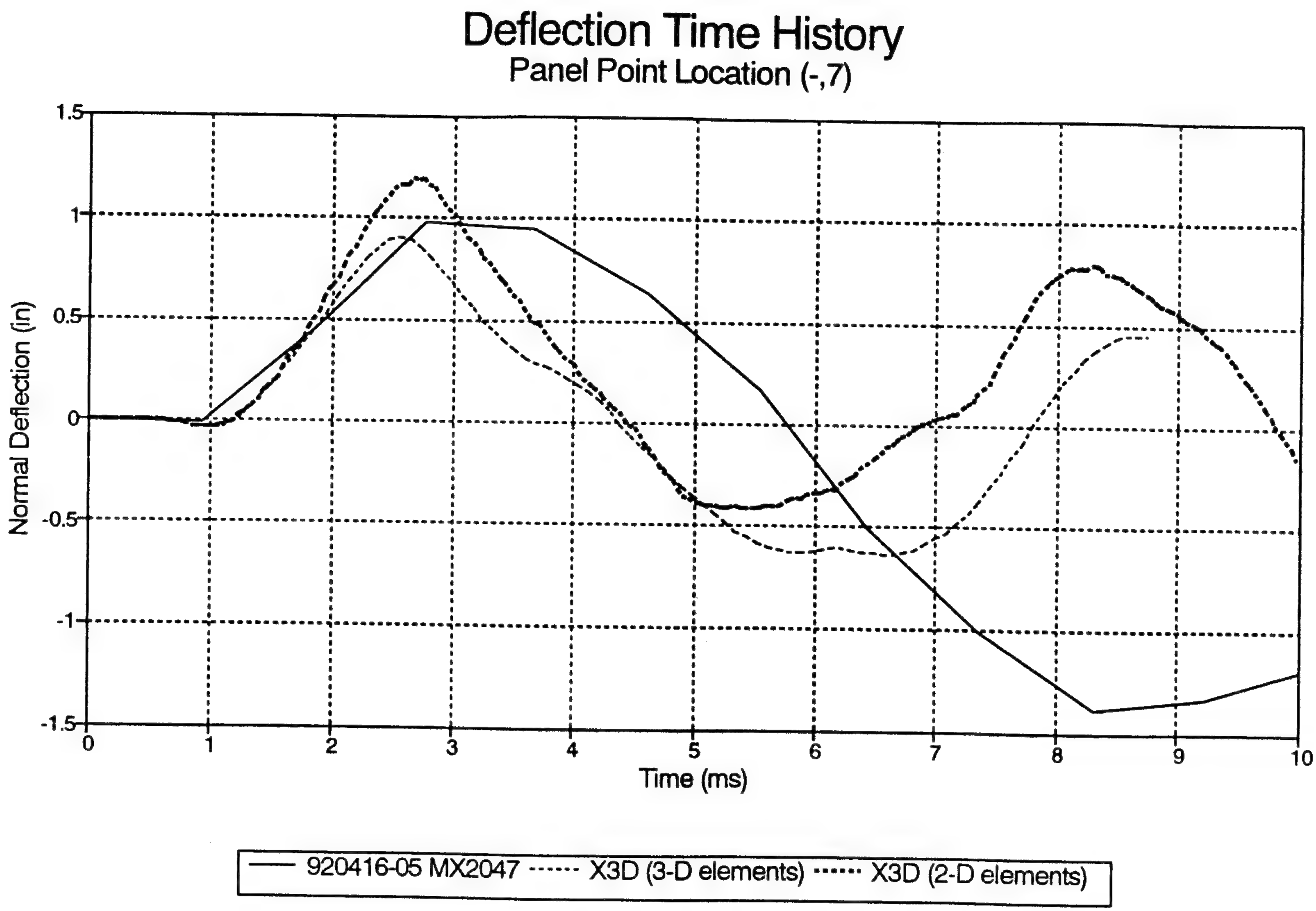


Figure 73. Triangulation/X3D Results Comparison at Panel Point Location (-,7).

and, in general, for any transparency impacts. The two-dimensional models result in relatively small models which reduce solution time and expense and produce acceptable results.

The results from the X3D finite element analysis showed that X3D proved to be a useful tool in the study of bird impact analyses. The X3D solutions do not agree with the same accuracy over the entire cross-section of the panel centerline (moving fore to aft), nor over the entire time interval of study for this test program. However, the agreement obtained between the X3D simulation and the experimental results from impact through maximum initial deflection and the first rebound shows that X3D is a viable tool in the simulation of a birdstrike. Development work is continuing on improved material models and on different methods of applying boundary conditions to simulate the actual birdstrike with improved accuracy.

SECTION 5
TENSILE COUPON EVALUATION

A series of tensile tests was performed on coupons cut from conical and flat panels. The objective of these tests was two-fold: first, to evaluate the differences in tensile response between the different resins used to mold the panels, and, second, to develop more data for use in defining parameters for the nonlinear viscoelastic/viscoplastic material models being developed for X3D. The procedures used in performing these tests is described in Section 5.1. Results of the tests are discussed in Section 5.2.

5.1 Tensile Test Methods

Two types of specimens were used for measuring tensile properties of the molded panels. These specimens, which have been shown in previous tests to provide similar results [2], are shown in Figure 74. The mini-tensile rod geometry was used for making coupons from the conical panels, which have no flat sections from which standard flat ASTM specimens can be machined. The ASTM D638 type III specimen profile was used for making coupons from flat panels.

The locations on the panels from which coupons were cut are shown in Figure 75. Although the ASTM standard specifies a maximum coupon thickness of 0.50 inches for this geometry, the two as-molded thicknesses of the panels (nominally 0.5 and 0.75 inches) were used for the ASTM tensile coupons. The mini-tensile rod coupons were machined from material in the center (of the through-the-thickness direction) of the cones.

Loading of the coupons was performed with MTS servohydraulic test equipment. Strains in the gage section of the specimens were captured using high-sensitivity extensometers. On the mini-tensile rod coupons a single axial extensometer was used to measure axial deformation. The initial gage length of this extensometer was 0.35 inch. On the ASTM coupons an axial and a diametral extensometer were used to capture axial extension and transverse contraction, respectively. The axial extensometer had an initial gage length of 2.0 inches, and the diametral

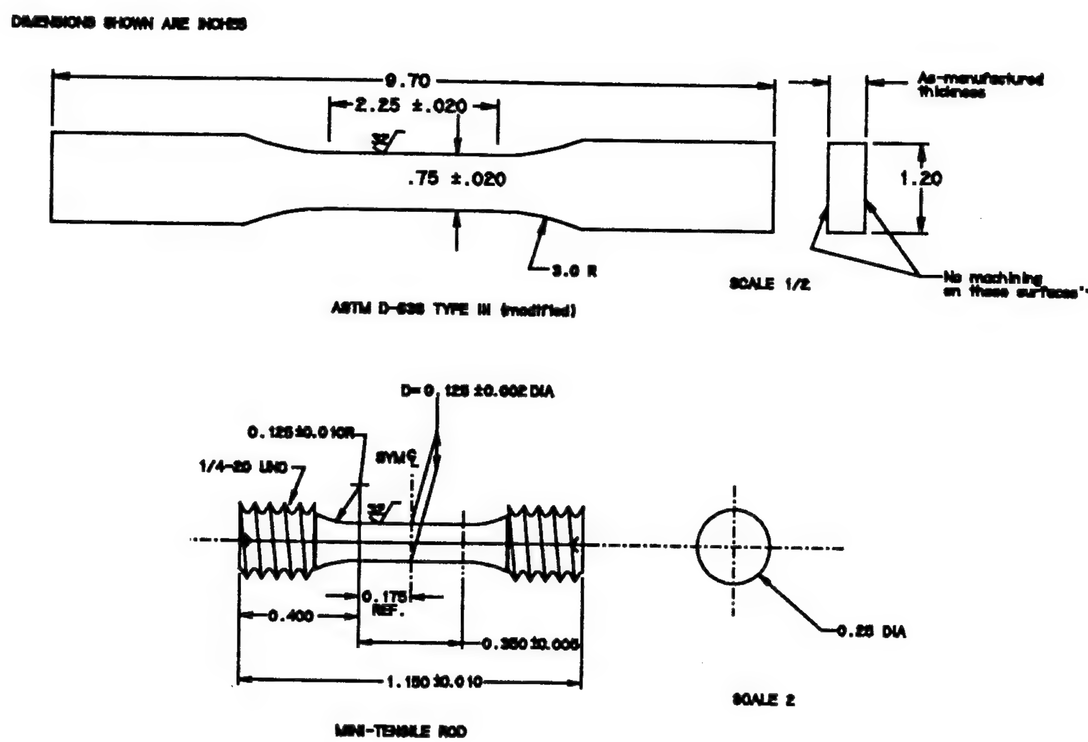


Figure 74. Specimens Used for Tension Tests on Flat and Conical Panels.

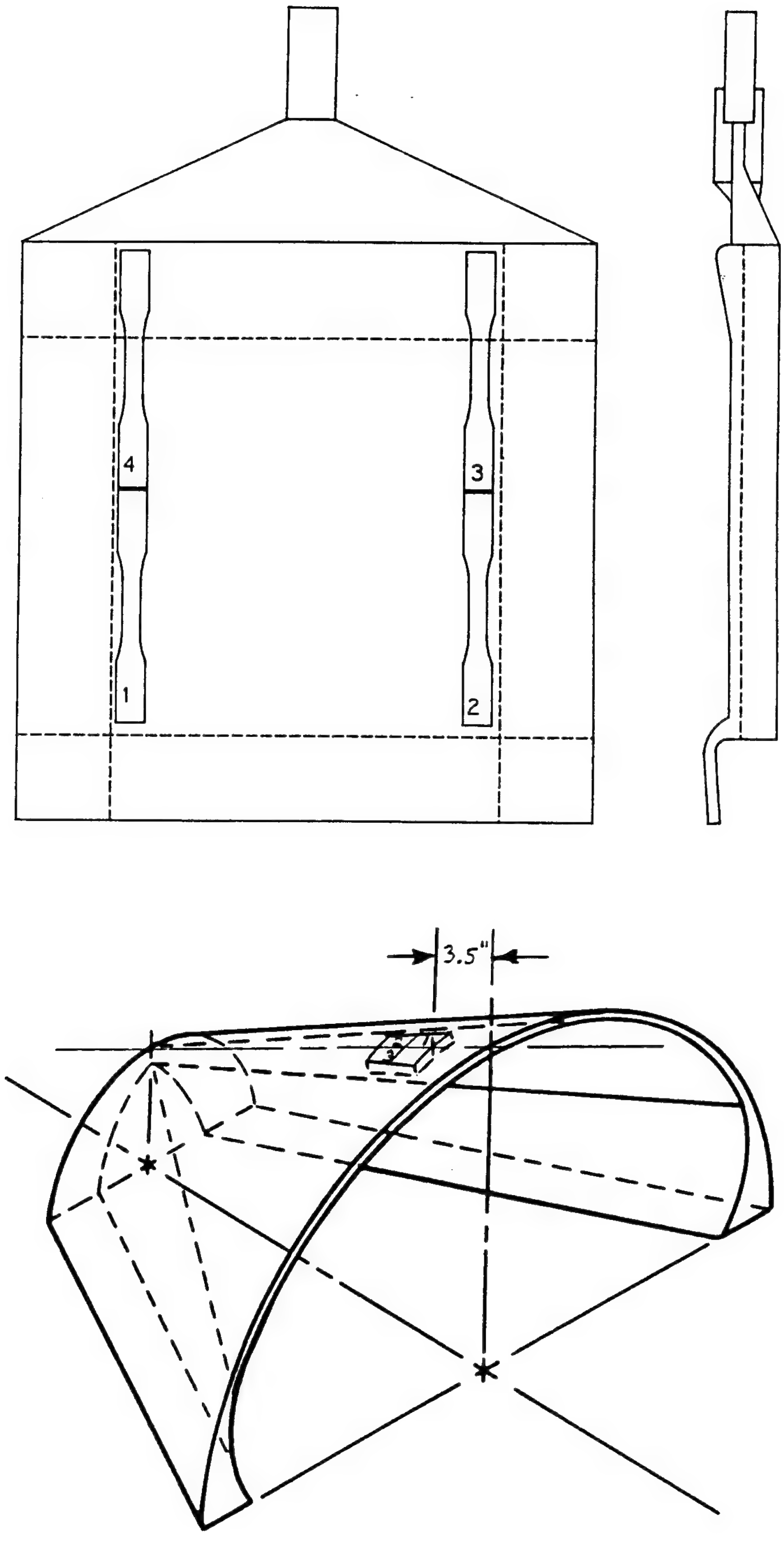


Figure 75. Locations of Tensile Coupons on Flat and Conical Panels.

extensometer had an initial gage length equal to the width of the coupon (nominally 0.75 inch). The ASTM specimen and extensometers are shown in Figure 76. Due to the limited displacement range of the axial extensometers (roughly 50% of the initial gage length) and the large displacements of the coupons at failure, linear extrapolation of the extensometer data was used to extend the strain data out to failure of the specimens.

In order to evaluate the variations in the material and to determine appropriate properties for use with new material models being developed for use with X3D, two sets of parameters were developed from the test data. The first set of parameters, referred to as "engineering" properties, identify key points on a stress-strain curve where the stress and strain values are based on initial length and cross sectional area of the specimen. These parameters, which were generated for all of the coupons tested, were used for evaluating differences between the different resins and molding processes. A second set of values, referred to as "true" engineering properties, were developed based on the existing length and cross sectional area of the specimen during the progression of the test. These parameters, which were developed only for the coupons cut from the flat panels, will be used to aid in defining appropriate constants for new material models being developed for X3D. The following paragraphs describe the equations used for reducing the measured quantities (load, displacement and specimen geometry) to mechanical properties.

The engineering stress S and axial engineering strain e^a are defined in terms of the load P, extension ℓ, initial area A_0, and initial length ℓ_0 as:

$$S = \frac{P}{A_0} \tag{5.1}$$

$$e^{a} = \frac{\ell - \ell_0}{\ell_0} \tag{5.2}$$

Also, the transverse engineering strain e^t can be defined in terms of terms of the width w and initial width w_0 as:

$$e^{t} = \frac{w - w_0}{w_0} \tag{5.3}$$

Note that lateral contraction of the specimen during the test produces a negative transverse strain.

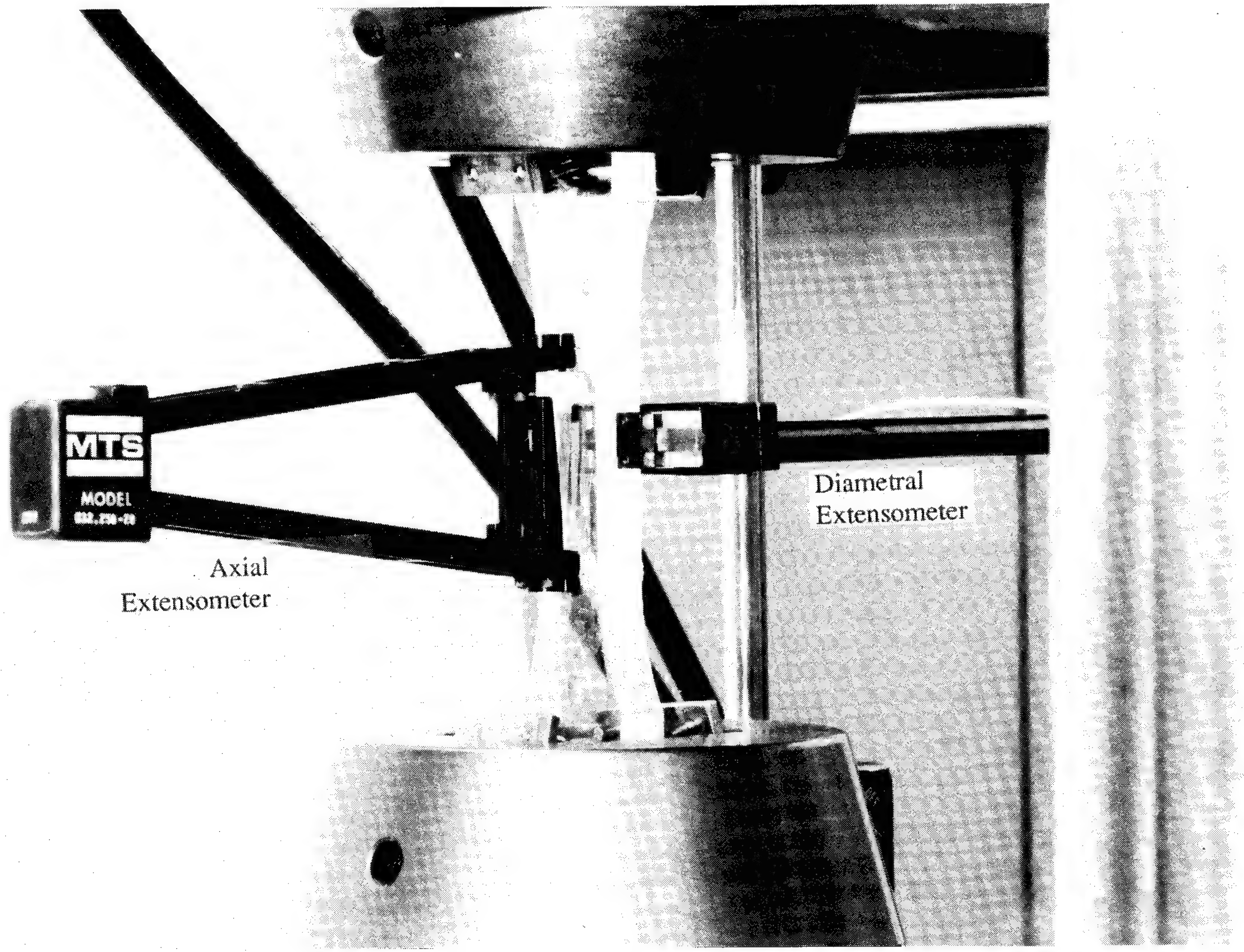


Figure 76. Extensometer Placement on Flat Panel Evaluation Specimen.

Figure 77 shows typical engineering stress-strain data for polycarbonate. The key engineering properties used for comparing the materials are identified in the figure. The strength (stress) and elongation (strain) at yield are defined (for this evaluation) as the point where the slope changes from positive to negative. The plastic strength reduction is the drop in stress immediately after yield. This decrease in strength is due to the formation of a neck at one location in the specimen which subsequently travels down the length of the specimen. The neck typically reaches the shoulders at the ends of the gage section at engineering strains of 0.8 to 1.0. At this point the stress begins to increase until the specimen ruptures. Initial modulus, defined as the tangent to the stress-strain curve at zero strain, was also used to compare the materials.

Figure 78 shows true stress-strain data which correspond to the engineering stress-strain data in Figure 77. Based on the assumption that the material is isotropic, the true stress σ, the true axial strain ε^a, and the true transverse strain ε^t can be defined in terms of the engineering quantities as:

$$\sigma = \frac{S}{(1 + e^{t})^2} \tag{5.4}$$

$$\varepsilon^a = \ln(1 + e^{a}) \tag{5.5}$$

$$\varepsilon^t = \ln(1 + e^{t}) \tag{5.6}$$

These definitions are only correct up to the yield point. Beyond this point the local stress and strain in the yielded area are not the same as S and e^a, which are average values over the entire gage section. Also, e^t is correct only for the location of the diametral extensometer, which is not necessarily the location where the necking initiates.

Once the necked region extends out to the ends of the gage section, the axial true strain given in Equation 5.5 is again approximately correct. Thus, the true strain at failure $\varepsilon^a{}_f$ can be determined from the engineering strain at rupture $e^a{}_f$ as:

$$\varepsilon^a{}_f = \ln(1 + e^{a}{}_f) \tag{5.7}$$

Assuming that elastic recovery is equal to the strain at yield, the true stress at failure σ_f can be approximated from the engineering stress at failure S_f, the initial cross sectional area A_0, the

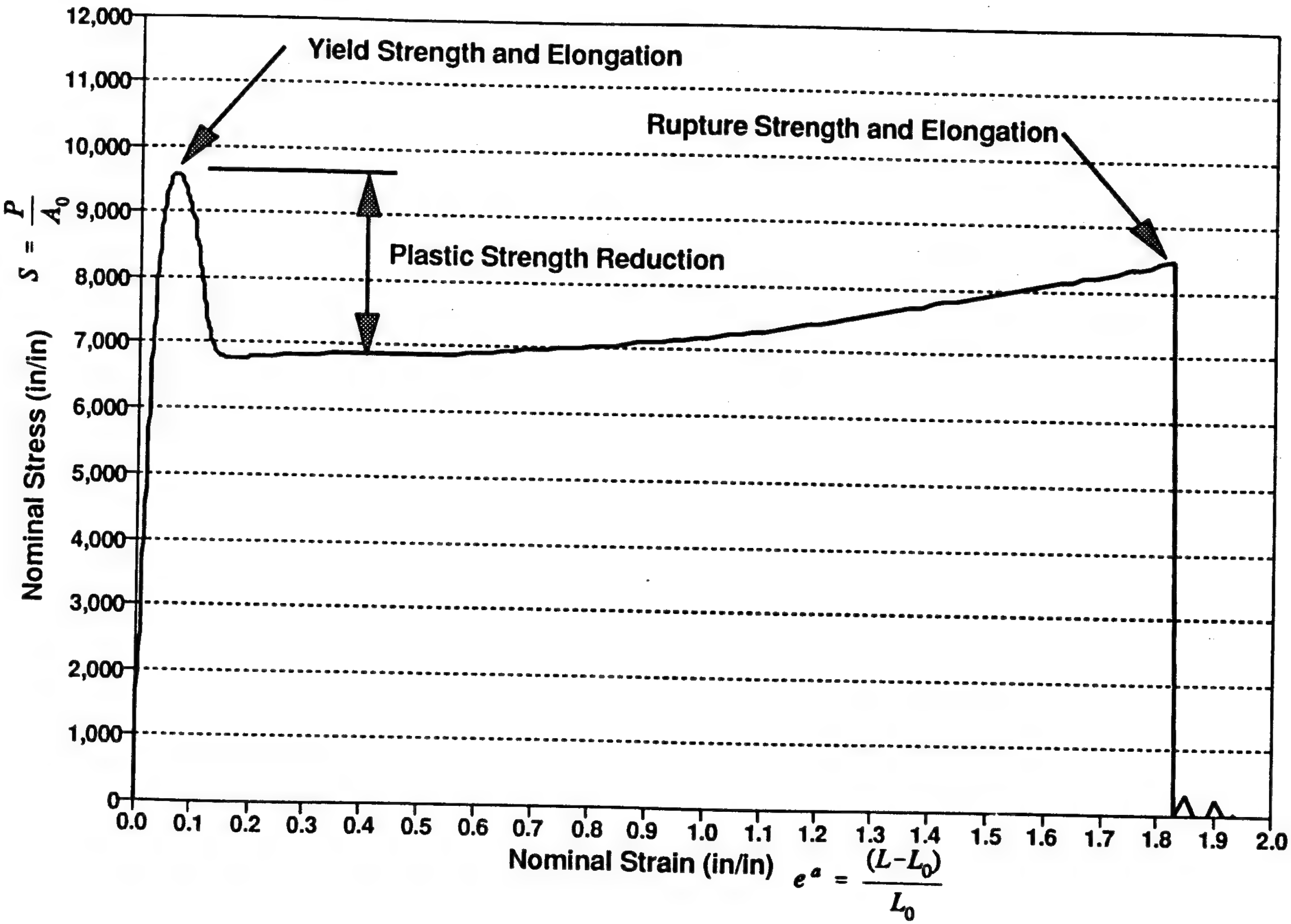


Figure 77. Tensile Test Engineering Parameters Used for Comparison of Materials.

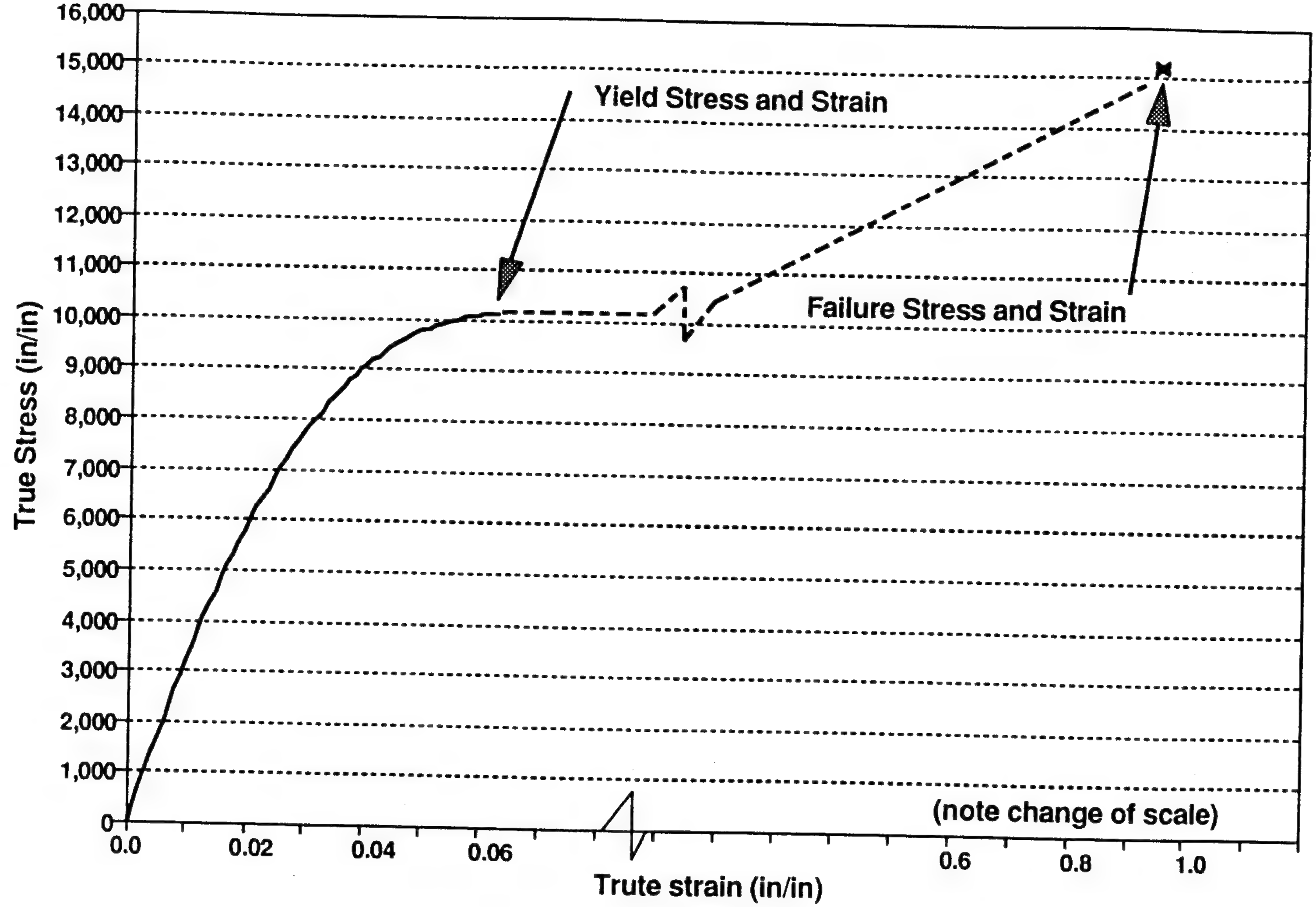


Figure 78. Typical True Stress-Strain Data.

cross sectional area after the specimen has ruptured A_r, and the transverse engineering strain at yield e^t_y as:

$$\sigma_f = \frac{S_f A_0}{A_r \, (1 + e^t_y)^2} \tag{5.8}$$

Equations 5.7 and 5.8 are used to define the failure stress and strain shown in Figure 78. In between yield and failure the true stress and strain cannot easily be determined experimentally. Analysis has shown that a true stress-strain curve which drops slightly or remains flat and then begins to rise with increasing strain (such as is shown by the dotted line in Figure 78) will produce an engineering stress strain curve similar to that shown in Figure 77 [9, 10]. No attempt has been made here to define the exact shape of the true stress-strain curve between yielding and failure.

It has been found that a cubic polynomial provides a very accurate characterization of the true stress-strain curve and true transverse strain-axial strain curves up to yield. Thus σ and ε^t can be expressed in terms of ε^a and constants from a least squares curve fit:

$$\sigma = C_1 \, \varepsilon^a + C_2 \, (\varepsilon^a)^2 + C_3 \, (\varepsilon^a)^3 \tag{5.9}$$

$$\varepsilon^t = B_1 \, \varepsilon^a + B_2 \, (\varepsilon^a)^2 + B_3 \, (\varepsilon^a)^3 \tag{5.10}$$

This allows the tangent modulus E and Poisson's ratio ν to be expressed as:

$$E = \frac{\partial \sigma}{\partial \varepsilon} = C_1 + 2 \, C_2 \, \varepsilon^a + 3 \, C_3 \, (\varepsilon^a)^2 \tag{5.11}$$

$$\nu = \frac{-\partial \varepsilon^t}{\partial \varepsilon^a} = - B_1 - 2 \, B_2 \, \varepsilon^a - 3 \, B_3 \, (\varepsilon^a)^2 \tag{5.12}$$

5.2 Tensile Test Results

Tensile tests were performed in two stages. First, tests were performed on a total of 30 mini-tensile rod coupons (3 coupons from each of 8 conical panels, plus 6 coupons from an 0.46-inch thick extruded panel of Rhom & Haas Tuffak A). These tests were used to identify variations among the properties of the resins when molded in a configuration similar to the CFT. Results of these tests are discussed in Section 5.2.1. Second, tests were performed on a total of 68 ASTM D638 type III coupons (4 coupons from each of 16 flat panels plus 4 coupons of 0.46-

inch thick extruded Tuffak A). These tests were used to confirm the results of the conical panel evaluation and to generate true stress-strain data appropriate for the new material model being developed for X3D. Results of these tests are discussed in Section 5.2.2.

5.2.1 Conical Panel Evaluation

All tests on the conical panel coupons were conducted at a temperature of 73°F and a nominal strain rate of 0.5 in/in/sec. For each of the four resins evaluated, coupons were cut from two panels. Two of the three coupons from each panel were tested with extensometers to provide good resolution of the strain data during the initial portion of the test. However, since past tests have shown that failure often initiates at the extensometer attachment locations on this specimen geometry, an extensometer was not attached to the third coupon from each set of three. Coupons without extensometers were used to provide an unbiased measure of the failure point for the materials.

Engineering properties measured for all of the coupons cut from conical panels are listed in Table 19. Average properties for each of the resins, plus results of tests in 1991 [2], are summarized in Table 20. Figures 79, 80, and 81 show average initial modulus, yield strength, and elongation at rupture, respectively. In Table 21, as well as the figures, sample standard deviation is used as a measure of the scatter in the data. Although the number of specimens (between two and six) on which the averages are based is too low to be a statistically meaningful sample, standard deviation has been used here as a convenient means of quantifying the scatter in the data. In each of the figures, error bars are included which are ±2 sample standard deviation from average, which is the band in which 95% of the data should lie if the limited amount of data are representative of a large sample with Gaussian distribution.

Figure 79 shows the initial modulus of each of the materials. Among the Dow 300-class resins molded in 1992, the average initial modulus increases slightly with increasing melt flow index (MFI). However, this change is small compared to the variability in the data and may not be significant. The initial modulus of the Dow 300-5 molded in 1991 (which was

Table 19. Results of Tensile Tests on Conical Panel Coupons (Mini-Tensile Rod Geometry) at 0.5/sec Nominal Strain Rate.

				TEST CONDITIONS			VALUES FROM ENGINEERING STRESS-STRAIN DATA					
Panel ID	Process ID	Sample ID		Measured Elastic Strain Rate (in/in/sec)	Measured Plastic Strain Rate (in/in/sec)	Initial Cross-Sectional Area (sq. in.)	Engineering Tensile Strength at Yield (psi)	Percent Elongation at Yield	Plastic Strength Reduction (psi)	Engineering Tensile Strength at Rupture** (psi)	Percent Elongation at Rupture**	Initial Modulus (psi)
DOW 300-4												
920422-04	MX2055	Q1	*	0.221	2.111	0.0121	10,023	7.07%	2,100	9,615	161%	352,056
		Q2	*	0.296	2.108	0.0121	9,972	6.48%	2,130	9,249	178%	367,430
		Q3		--	--	0.0121	9,781	--	1,780	12,159	254%	--
920422-05	MX2055	R1	*	0.479	1.920	0.0121	10,063	6.49%	2,200	10,312	162%	394,903
		R2	*	0.326	2.158	0.0119	9,989	6.99%	2,140	7,990	81%	364,915
		R3		--	--	0.0121	10,112	--	2,260	12,867	279%	--
		Average		0.330	2.074	0.0120	9,990	6.76%	2,102	12,513	267%	369,826
		Std. Dev.		(0.11)	(0.11)	(0.0001)	(114)	(0.0032)	(168)	(501)	(0.17)	(18,023)
DOW 300-6												
920421-04	MX2056	S1	*	0.370	2.102	0.0121	10,308	5.99%	2,360	9,643	158%	398,874
		S2	*	0.388	2.013	0.0121	10,242	6.82%	2,290	8,364	117%	360,720
		S3		--	--	0.0121	10,255	--	2,400	11,088	203%	--
920421-05	MX2055	T1	*	0.447	2.382	0.0121	10,043	7.36%	2,270	10,081	204%	339,152
		T2	*	0.463	2.457	0.0121	10,134	6.88%	2,230	8,079	122%	407,352
		T3		--	--	0.0121	10,326	--	2,500	12,377	304%	--
		Average		0.417	2.239	0.0121	10,218	6.76%	2,342	11,733	254%	376,525
		Std. Dev.		(0.05)	(0.21)	0.0000	(109)	(0.0057)	(99)	(911)	(0.71)	(32,126)
DOW 300-15												
920421-06	MX2057	U1	*	0.291	1.980	0.0121	10,267	6.68%	2,370	7,930	74%	360,335
		U2	*	0.432	2.152	0.0119	10,333	6.38%	2,390	9,765	177%	400,157
		U3		--	--	0.0121	10,292	--	2,490	9,760	176%	--
920421-05	MX2057	V1	*	0.394	2.071	0.0119	10,302	6.42%	2,540	9,733	97%	432,768
		V2	*	0.414	1.997	0.0121	10,471	6.16%	2,490	9,919	153%	364,057
		V3		--	--	0.0119	10,401	--	2,530	11,131	234%	--
		Average		0.383	2.050	0.0120	10,344	6.41%	2,468	10,446	205%	389,329
		Std. Dev.		(0.06)	(0.08)	(0.0001)	(77)	(0.0022)	(72)	(969)	(0.41)	(34,076)
DOW XU73093-5.5												
920421-04	MX2058	W1	*	0.536	2.117	0.0119	10,274	6.59%	2,380	10,072	181%	391,895
		W2	*	0.575	2.244	0.0121	10,102	6.54%	2,370	10,204	206%	383,844
		W3		--	--	0.0121	10,170	--	2,420	12,368	303%	--
920421-05	MX2058	X1	*	0.419	1.857	0.0121	10,123	5.75%	2,380	10,306	167%	404,430
		X2	*	0.273	1.911	0.0121	10,327	6.63%	2,320	9,202	132%	379,812
		X3		--	--	0.0119	10,501	--	2,490	11,844	232%	--
		Average		0.450	2.032	0.0120	10,250	6.38%	2,393	12,106	267%	389,995
		Std. Dev.		(0.14)	(0.18)	(0.0001)	(151)	(0.0042)	(57)	(371)	(0.50)	(10,855)
Rhom & Haas Tuffak A												
Extruded		1	*	0.296	2.061	0.0121	10,964	6.03%	2,700	11,004	195%	417,535
Polycarbonate		2	*	0.292	2.083	0.0121	10,860	6.14%	2,720	9,854	155%	386,043
		3		--	--	0.0123	11,048	--	2,730	12,533	247%	--
		4	*	0.266	1.886	0.0119	10,675	6.08%	2,670	10,251	170%	392,043
		5	*	0.255	2.401	0.0117	10,889	6.48%	2,740	11,438	244%	404,060
		6		--	--	0.0117	10,945	--	2,700	11,033	201%	--
		Average		0.277	2.108	0.0119	10,897	6.18%	2,710	11,783	224%	399,920
		Std. Dev		(0.02)	(0.21)	(0.0002)	(127)	(0.0020)	(25)	(1,061)	(0.33)	(13,929)

*Indicates specimen tested with extensometer attached.

**Average at rupture based only on specimens without extensometer.

Table 20. Summary of Properties Measured with Mini-Tensile Rod Specimens at 0.5/sec Nominal Strain Rate.

	Engineering Tensile Strength at Yield (psi)	Percent Elongation at Yield	Plastic Strength Reduction (psi)	Engineering Tensile Strength at Rupture (psi)	Percent Elongation at Rupture	Initial Modulus (psi)
Injection Molded Materials						
DOW 300-4	9,990	6.8%	2,102	12,513	267%	369,826
DOW 300-6	10,218	6.8%	2,342	11,733	254%	376,525
DOW 300-15	10,344	6.4%	2,468	10,446	205%	389,329
DOW XU73093-5.5	10,250	6.4%	2,393	12,106	267%	389,995
DOW 300-5 (tested 1991)	10,440	6.5%	2,346	--	137%	361,000
Extruded materials						
R & H Tuffak A	10,897	6.2%	2,710	11,783	224%	399,920
GE 9034-112 (tested 1991)	11,058	6.9%	2,718	--	195%	373,200

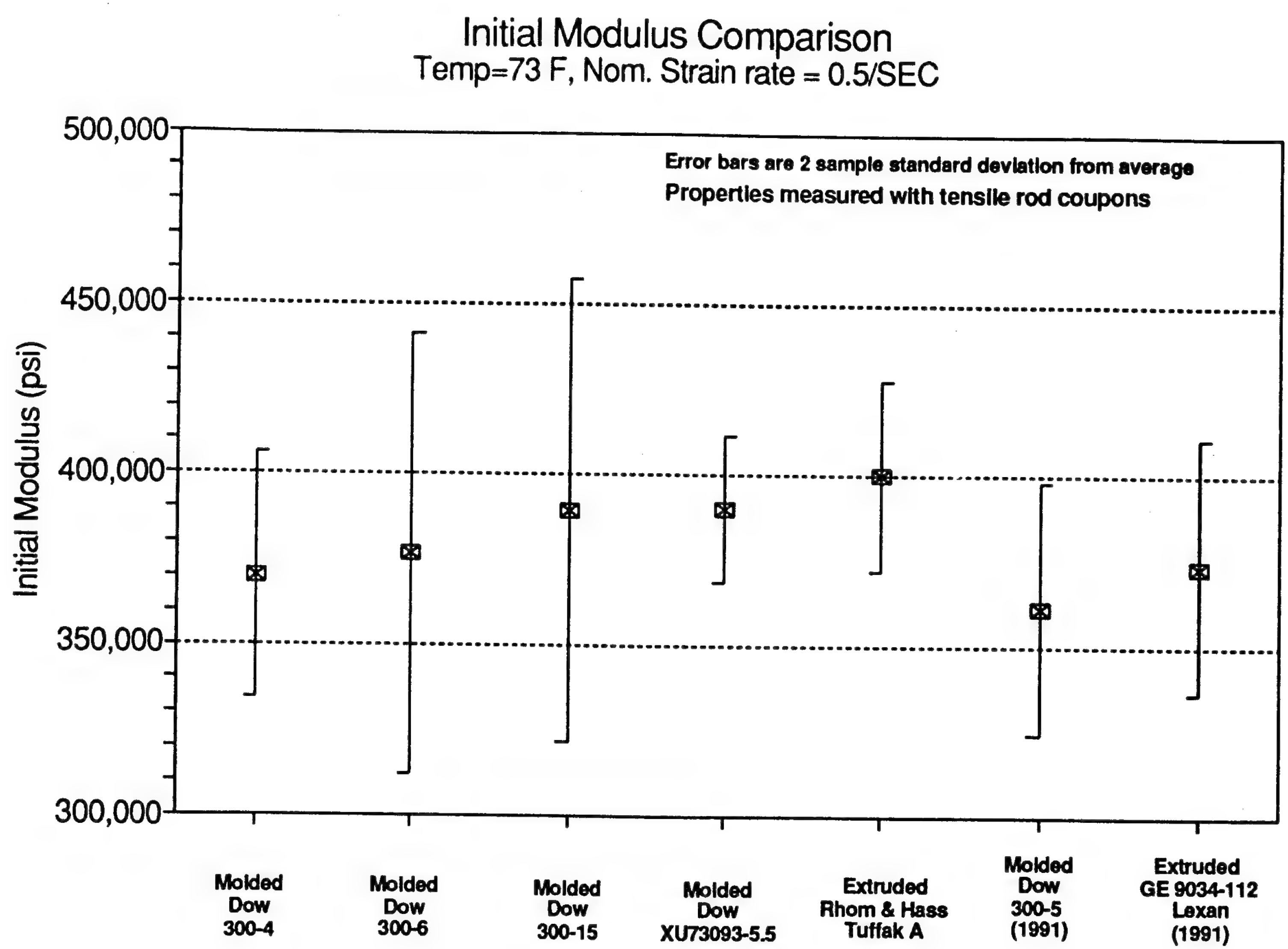


Figure 79. Conical Panel Tensile Properties Comparison - Initial Modulus.

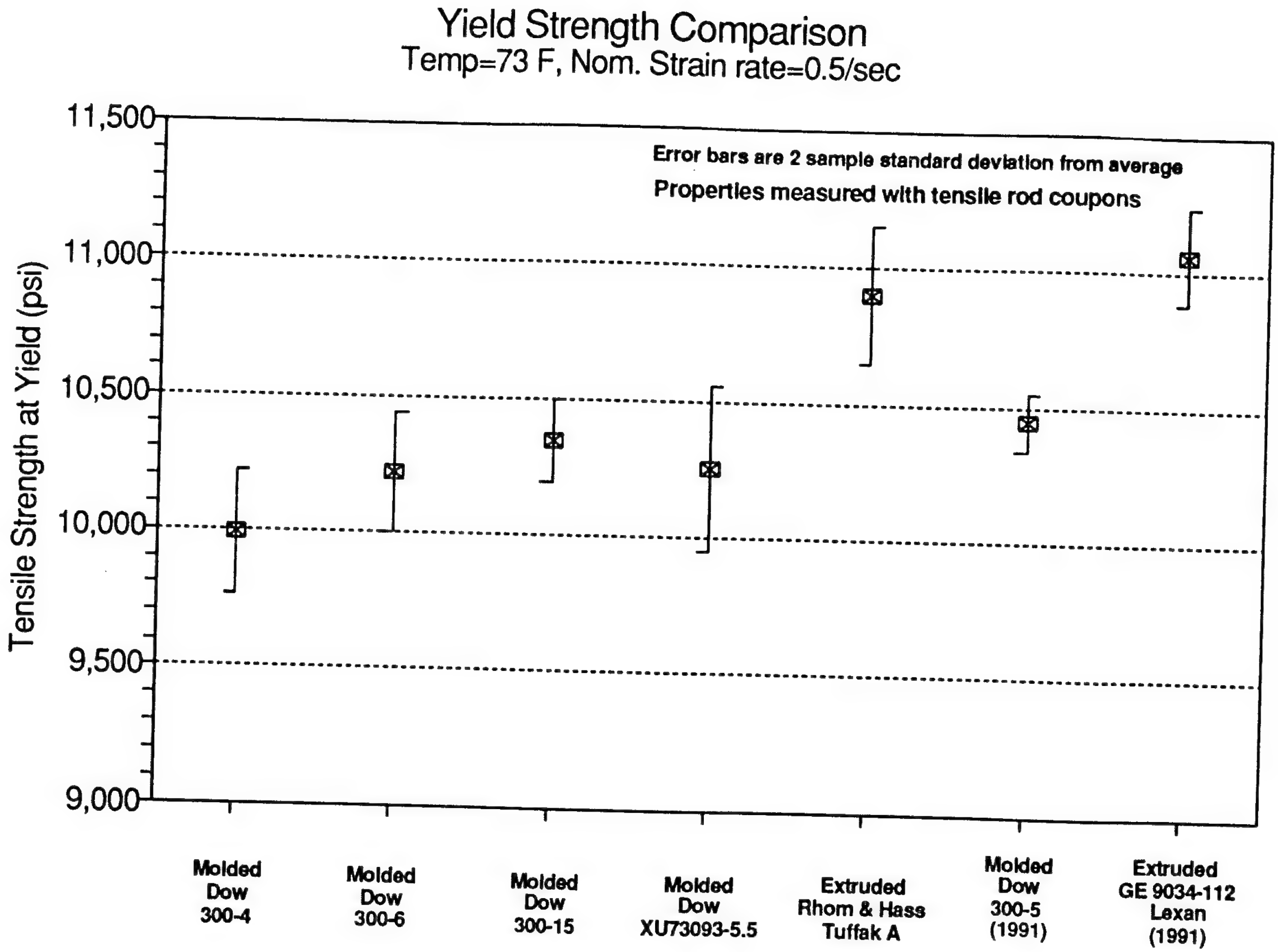


Figure 80. Conical Panel Tensile Properties Comparison - Yield Strength.

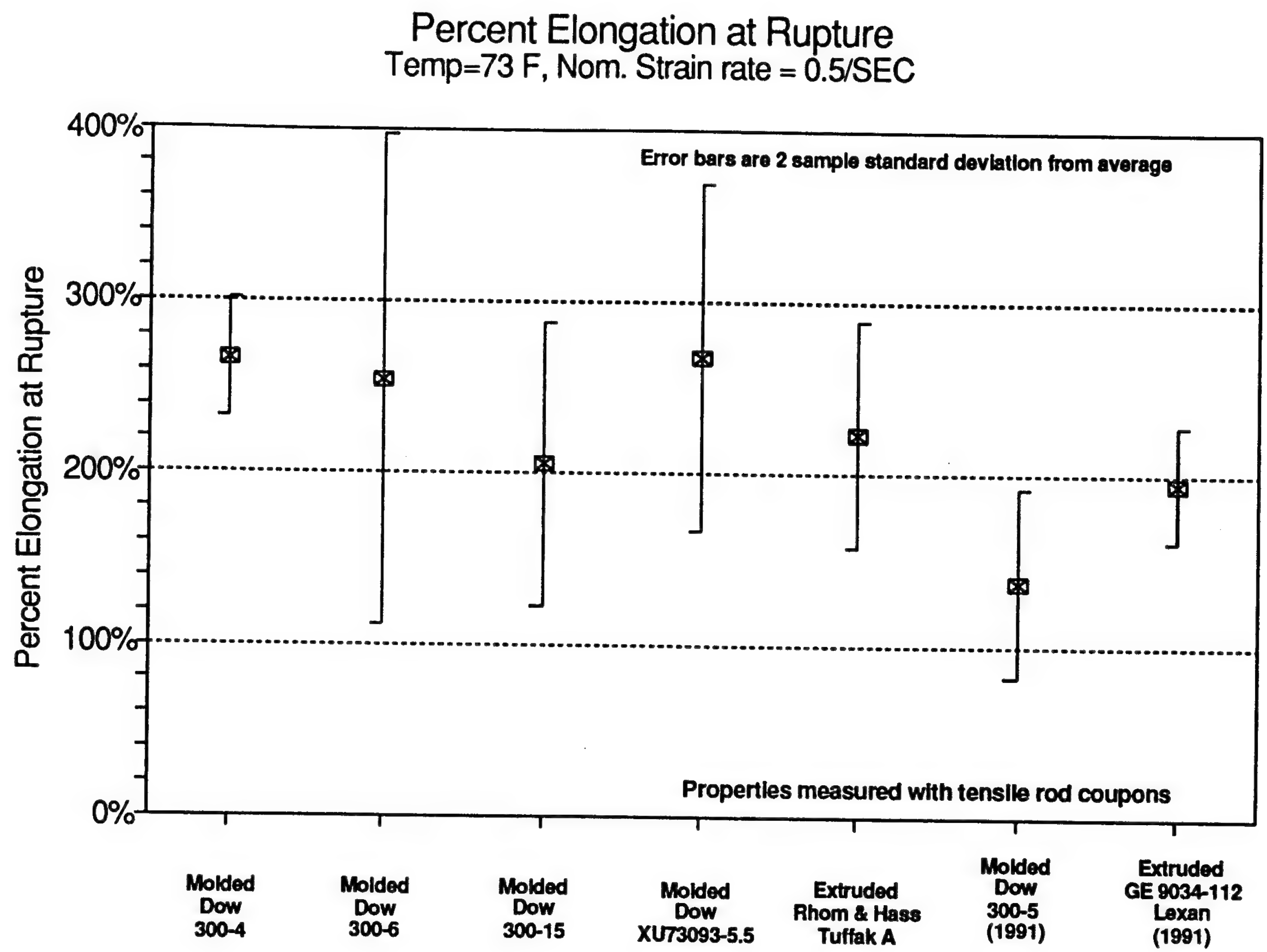


Figure 81. Conical Panel Tensile Properties Comparison - Elongation at Rupture.

Table 21. Results of Tensile Tests on Flat Panel Coupons (ASTM D638 Type III Geometry).

Resin	Nom. Panel Thick (in)	Process	Panel ID	Coupon ID	Nominal Elastic Strain Rate (1/sec)	Measured Elastic Strain Rate (1/sec)	Measured Plastic Strain Rate (1/sec)	Initial Cross Sectional Area (sq. in.)	Cross Sectional Area After Rupture (sq. in.)	Engineering Tensile Strength at Yield (psi)	Percent Elongation at Yield	Plastic Strength Reduction (psi)	Engineering Tensile Strength at Rupture (psi)	Percent Elongation at Rupture
DOW 300-4	3/4	MX2047	920416-06	A-1	0.005	0.0045	0.0132	0.5693	0.3003	9,726	6.4%	2,726	8,863	198%
				A-2	0.005	0.0045	0.0130	0.5753	0.3041	9,388	6.3%	2,738	8,216	180%
			920416-09	B-1	0.005	0.0044	0.0131	0.5715	0.3019	9,378	6.4%	2,778	8,268	188%
				B-2	0.005	0.0047	0.0123	0.5730	0.3119	9,635	6.5%	2,785	8,121	154%
			920416-06	A-3	0.5	0.2151	2.0139	0.5888	0.3539	10,369	7.4%	2,669	8,103	82%
				A-4	0.5	0.2048	2.1629	0.5639	0.3279	10,500	7.3%	2,600	8,274	90%
			920416-09	B-3	0.5	0.1563	2.1900	0.5896	0.3185	10,706	7.3%	2,706	8,027	19%
				B-4	0.5	---	---	---	---	---	---	---	---	---
	1/2	MX2051	920415-03	I-1	0.005	---	---	---	---	---	---	---	---	---
				I-2	0.005	0.0052	0.0130	0.3825	0.1910	9,243	6.5%	2,693	9,382	234%
			920415-08	J-1	0.005	0.0052	0.0129	0.3797	0.2050	9,289	6.4%	2,639	9,409	180%
				J-2	0.005	---	---	---	---	---	---	---	---	---
			920415-03	I-3	0.5	0.1871	1.8550	0.3960	0.2082	10,359	7.2%	2,509	9,581	144%
				I-4	0.5	0.1910	1.5685	0.3958	0.2299	10,470	7.1%	2,470	8,596	80%
			920415-08	J-3	0.5	0.1833	2.1518	0.3945	0.2040	10,644	7.4%	2,544	9,963	170%
				J-4	0.5	0.1791	2.0226	0.3960	0.2146	10,408	7.3%	2,508	9,362	144%
DOW 300-6	3/4	MX2048	920414-04	C-1	0.005	0.0046	0.0127	0.5738	0.2965	9,677	6.5%	2,777	8,655	184%
				C-2	0.005	0.0047	0.0131	0.5738	0.3091	9,481	6.4%	2,806	8,139	176%
			920414-06	D-1	0.005	0.0047	0.0131	0.5723	0.3203	9,622	6.5%	2,822	7,916	150%
				D-2	0.005	0.0046	0.0124	0.5738	0.2981	9,573	6.4%	2,873	8,481	180%
			920414-04	C-3	0.5	0.2059	1.8263	0.5896	0.3351	10,653	7.3%	2,653	8,423	84%
				C-4	0.5	0.1761	1.8694	0.5873	0.3174	10,661	7.3%	2,661	9,244	126%
			920414-06	D-3	0.5	0.2103	2.0923	0.5850	0.3079	10,735	7.2%	2,735	9,240	138%
				D-4	0.5	0.1613	2.1386	0.5865	0.3180	10,755	7.2%	2,705	9,348	142%
	1/2	MX2052	920414-02	K-1	0.005	0.0054	0.0124	0.3818	0.2130	9,513	6.3%	2,663	8,247	156%
				K-2	0.005	0.0052	0.0130	0.3825	0.1931	9,277	6.4%	2,627	8,825	214%
			920414-08	L-1	0.005	0.0052	0.0129	0.3805	0.1977	9,457	6.3%	2,707	8,704	198%
				L-2	0.005	0.0052	0.0129	0.3825	0.2174	9,309	6.1%	2,659	7,701	144%
			920414-02	K-3	0.5	0.2100	1.4950	0.3968	0.2302	10,597	7.2%	2,547	8,396	64%
				K-4	0.5	0.2251	1.9951	0.3955	0.2345	10,211	7.0%	2,511	7,854	62%
			920414-08	L-3	0.5	0.1838	1.8559	0.3962	0.2220	10,559	7.1%	2,559	8,572	112%
				L-4	0.5	0.1801	1.7272	0.3955	0.2306	10,528	7.2%	2,527	8,258	66%

Table 21. Results of Tensile Tests on Flat Panel Coupons (ASTM D638 Type III Geometry) (concluded).

Resin	Nom. Panel Thick (in)	Process	Panel ID	Coupon ID	Nominal Elastic Strain Rate (1/sec)	Measured Elastic Strain Rate (1/sec)	Measured Plastic Strain Rate (1/sec)	Initial Cross Sectional Area (sq. in.)	Cross Sectional Area After Rupture (sq. in.)	Engineering Tensile Strength at Yield (psi)	Percent Elongation at Yield	Plastic Strength Reduction (psi)	Engineering Tensile Strength at Rupture (psi)	Percent Elongation at Rupture
DOW 300-15	3/4	MX2049	920413-03	E-1	0.005	---	---	---	---	---	---	---	---	---
				E-2	0.005	0.0047	0.0120	0.5617	0.3283	9,577	6.5%	2,877	6,813	50%
			920413-04	F-1	0.005	0.0046	0.0131	0.5745	0.3158	9,560	6.3%	2,860	7,655	144%
				F-2	0.005	0.0047	0.0129	0.5753	0.3469	9,542	6.3%	2,842	6,816	68%
			920413-03	E-3	0.5	---	---	---	---	---	---	---	---	---
				E-4	0.5	0.1822	1.8049	0.5708	0.3370	10,531	7.0%	2,731	7,990	52%
			920413-04	F-3	0.5	0.1769	1.7131	0.5880	0.3084	10,677	7.1%	2,777	9,340	130%
				F-4	0.5	0.1665	2.1833	0.5888	0.3063	10,650	7.2%	2,750	9,300	146%
	1/2	MX2053	920414-03	M-1	0.005	0.0053	0.0123	0.3830	0.2093	9,383	6.2%	2,683	8,059	160%
				M-2	0.005	0.0053	0.0128	0.3827	0.2162	9,373	6.2%	2,723	7,413	132%
			920414-07	N-1	0.005	0.0053	0.0109	0.3818	0.1991	9,587	6.3%	2,687	8,588	166%
				N-2	0.005	0.0051	0.0125	0.3820	0.2243	9,524	6.0%	2,674	6,939	54%
			920414-03	M-3	0.5	0.1785	1.7799	0.3968	0.2119	10,552	7.2%	2,602	9,141	126%
				M-4	0.5	0.1765	1.8076	0.3960	0.2184	10,456	6.9%	2,556	8,483	100%
			920414-07	N-3	0.5	0.1826	1.8140	0.3960	0.2203	10,708	7.1%	2,608	8,370	64%
				N-4	0.5	0.2048	1.6546	0.3965	0.2213	10,419	7.0%	2,619	8,169	78%
DOW XU73093-5.5	3/4	MX2050	920415-03	G-1	0.005	0.0046	0.0120	0.5746	0.3153	9,384	6.3%	2,784	7,943	152%
				G-2	0.005	---	---	---	---	---	---	---	---	---
			920415-08	H-1	0.005	---	---	---	---	---	---	---	---	---
				H-2	0.005	---	---	---	---	---	---	---	---	---
			920415-03	G-3	0.5	0.1753	1.9989	0.5865	0.3242	10,450	7.4%	2,700	8,052	70%
				G-4	0.5	0.1657	2.0173	0.5881	0.3474	10,505	7.2%	2,605	8,113	70%
			920415-08	H-3	0.5	0.1650	2.0834	0.5916	0.3185	10,543	7.2%	2,593	9,237	152%
				H-4	0.5	0.1869	2.1219	0.5888	0.3334	10,473	7.2%	2,673	8,498	108%
	1/2	MX2054	920415-03	O-1	0.005	0.0052	0.0112	0.3810	0.1867	9,453	6.5%	2,603	9,644	212%
				O-2	0.005	0.0050	0.0129	0.3820	0.2020	9,396	6.2%	2,596	8,868	200%
			920415-08	P-1	0.005	0.0051	0.0103	0.3808	0.1958	9,285	6.1%	2,585	8,836	170%
				P-2	0.005	0.0051	0.0129	0.3825	0.2152	9,349	6.3%	2,599	9,146	218%
			920415-03	O-3	0.5	0.1798	1.7218	0.3960	0.2228	10,312	6.9%	2,462	8,113	108%
				O-4	0.5	0.1771	1.7221	0.3955	0.2076	10,471	7.1%	2,471	9,647	130%
			920415-08	P-3	0.5	0.2114	2.0299	0.3978	0.2329	10,500	7.0%	2,500	8,274	80%
				P-4	0.5	0.2262	1.7457	0.3942	0.2153	10,284	7.1%	2,534	9,664	142%
Extruded TUFFAK A	1/2	---	---	TST-1	0.005	0.0050	0.01303	0.3415	0.1750	9,641	6.3%	2,974	8,909	208%
				TST-2	0.005	0.0051	0.01294	0.3435	0.1766	9,283	6.5%	2,781	9,130	210%
				TST-3	0.5	0.2631	2.2761	0.3417	0.1799	10,895	7.2%	2,973	9,733	166%

measured on mini-tensile rod coupons cut from flat panels) is very close to that of the Dow 300-4 molded in 1992.

Figure 80 shows the yield strength of each of the materials. Among the Dow 300-class resins molded in 1992, the average yield strength increases slightly with increasing MFI. The consistency of the data indicates that this trend is probably statistically significant, but the small magnitude of the increase makes it unlikely that this change has any impact on the relative performance of the materials. It should be noted that the yield strength of the molded materials is 5-10% lower than that for either of the extruded materials.

Figure 81 shows the ultimate elongation of each material. Among the Dow 300-class resins molded in 1992, the average elongation at rupture decreases slightly with increasing MFI. Also, the elongation at rupture for all of the materials tested in 1992 is somewhat higher than that of those tested in 1991. This may be due to changes in the materials or to differences in surface finish of the machined specimens.

The combination of higher yield strength and lower elongation at rupture indicates that Dow 300-xx resins with higher MFIs are more brittle at these loading rates than those with lower MFIs. In general, however, the magnitude of these changes is small enough to lie within the scatter in the data and is unlikely to affect the physical performance of components made from any of the materials.

It should be noted that the yield strength of all of the molded materials is lower than that of the Dow 300-5 test in 1991, while the ultimate elongation is higher for all of the molded materials than that of the Dow 300-5. This indicates that the Dow 300-5 molded in 1991 was more brittle than any of the resins used to mold the conical panels in 1992. This may have been caused by differences in the material formulation or by differences in the molding methods used in 1992.

Finally, it should be noted that the bird impact analyses described in Section 4 were based on properties measured for the Dow 300-5 molded in 1991. The tensile tests

described in this section show that parameters used in the X3D analysis for yield and failure should be modified slightly for the materials molded in 1992. However the modulus of the Dow 300-5 is the same (within the scatter in the data) as that of the materials molded in 1992. Thus, the properties used in the analysis, which describe the elastic response, are correct for the materials molded in 1992. Since only elastic response occurred in the simulations, the material parameters used for X3D were adequate for panels molded in both 1991 and 1992.

5.2.2 Flat Panel Evaluation

Tests on the flat panel coupons were conducted at a temperature of 73°F and at nominal strain rates of 0.005 and 0.5 in/in/sec. For each of the four resins evaluated, coupons were fabricated from four panels: two 1/2-inch thick panels and two 3/4-inch thick panels. This allowed four tests to be run on each combination of resin (four resins), panel thickness (two thicknesses), and strain rate (two rates).

Engineering stress and strain results for each of the coupons are listed in Table 21. For a few of the coupons, no data are listed. These correspond to tests in which either the load or axial extensometer data were not properly captured during the test.

In general, the engineering stress and strain data from the ASTM specimens show even less variation due to changes in MFI than the mini-tensile rod specimen data for the cones. Averages of the engineering data for the (typically) four coupons at each combination of resin, panel thickness, and strain rate are summarized in Table 22. Figures 82 and 83 show yield strengths for the flat panel tests at 0.005 and 0.5 per-second strain rates; and Figures 84 and 85 show elongations to rupture.

Figures 82 and 83 indicate that, within the scatter in the data, the tensile strength at yield is the same for all three MFIs of Dow 300-xx material at both the 0.005 and 0.5 per-second strain rates. Also, comparison of Figures 80 and 83 shows that all of the yield strengths for the Dow 300-xx flat panel coupons are higher than those of the conical panel coupons, but are similar to the yield strength of the Dow 300-5 flat panel molded in 1991. This indicates that

Table 22. Summary of Engineering Properties Measured with Flat Panel Coupons (ASTM D638 Type III Geometry).

Resin	Nom. Panel Thick (in)	Process	Nominal Elastic Strain Rate (1/sec)	Measured Elastic Strain Rate (1/sec)	Measured Plastic Strain Rate (1/sec)	Initial Cross Sectional Area (sq. in.)	Cross Sectional Area After Rupture (sq. in.)	Engineerin g Tensile Strength at Yield (psi)	Percent Elongation at Yield	Plastic Strength Reduction (psi)	Engineering Tensile Strength at Rupture (psi)	Percent Elongation at Rupture
Dow 300-4	3/4	MX2047	0.005	0.0045	0.0129	0.5723	0.3046	9,532	6.4%	2,757	8,367	180%
	1/2	MX2051	0.005	0.0052	0.0130	0.3811	0.1980	9,266	6.5%	2,666	9,396	207%
	3/4	MX2047	0.5	0.1921	2.1222	0.5808	0.3334	10,525	7.3%	2,658	8,135	64%
	1/2	MX2051	0.5	0.1851	1.8995	0.3956	0.2142	10,470	7.3%	2,508	9,376	135%
Dow 300-6	3/4	MX2048	0.005	0.0046	0.0128	0.5734	0.3060	9,588	6.5%	2,820	8,298	173%
	1/2	MX2052	0.005	0.0053	0.0128	0.3818	0.2053	9,389	6.3%	2,664	8,369	178%
	3/4	MX2048	0.5	0.1884	1.9817	0.5871	0.3196	10,701	7.3%	2,689	9,064	123%
	1/2	MX2052	0.5	0.1997	1.7683	0.3960	0.2293	10,474	7.1%	2,536	8,270	76%
Dow 300-15	3/4	MX2049	0.005	0.0047	0.0126	0.5705	0.3303	9,560	6.4%	2,860	7,095	87%
	1/2	MX2053	0.005	0.0053	0.0121	0.3824	0.2122	9,467	6.2%	2,692	7,750	128%
	3/4	MX2049	0.5	0.1752	1.9004	0.5825	0.3172	10,619	7.1%	2,753	8,877	109%
	1/2	MX2053	0.5	0.1856	1.7640	0.3963	0.2180	10,534	7.1%	2,596	8,541	92%
Dow XU73093-15	3/4	MX2050	0.005	0.0046	0.0120	0.5746	0.3153	9,384	6.3%	2,784	7,943	152%
	1/2	MX2054	0.005	0.0051	0.0118	0.3816	0.2000	9,371	6.3%	2,596	9,124	200%
	3/4	MX2050	0.5	0.1732	2.0554	0.5888	0.3309	10,493	7.3%	2,643	8,475	100%
	1/2	MX2054	0.5	0.1986	1.8049	0.3959	0.2197	10,392	7.0%	2,492	8,925	115%
Ext. Tuffak A	1/2	---	0.005	0.0051	0.0130	0.3425	0.1758	9,462	6.4%	2,878	9,020	209%
	1/2	---	0.5	0.2735	2.2963	0.3425	0.1837	10,858	7.3%	2,929	9,413	152%

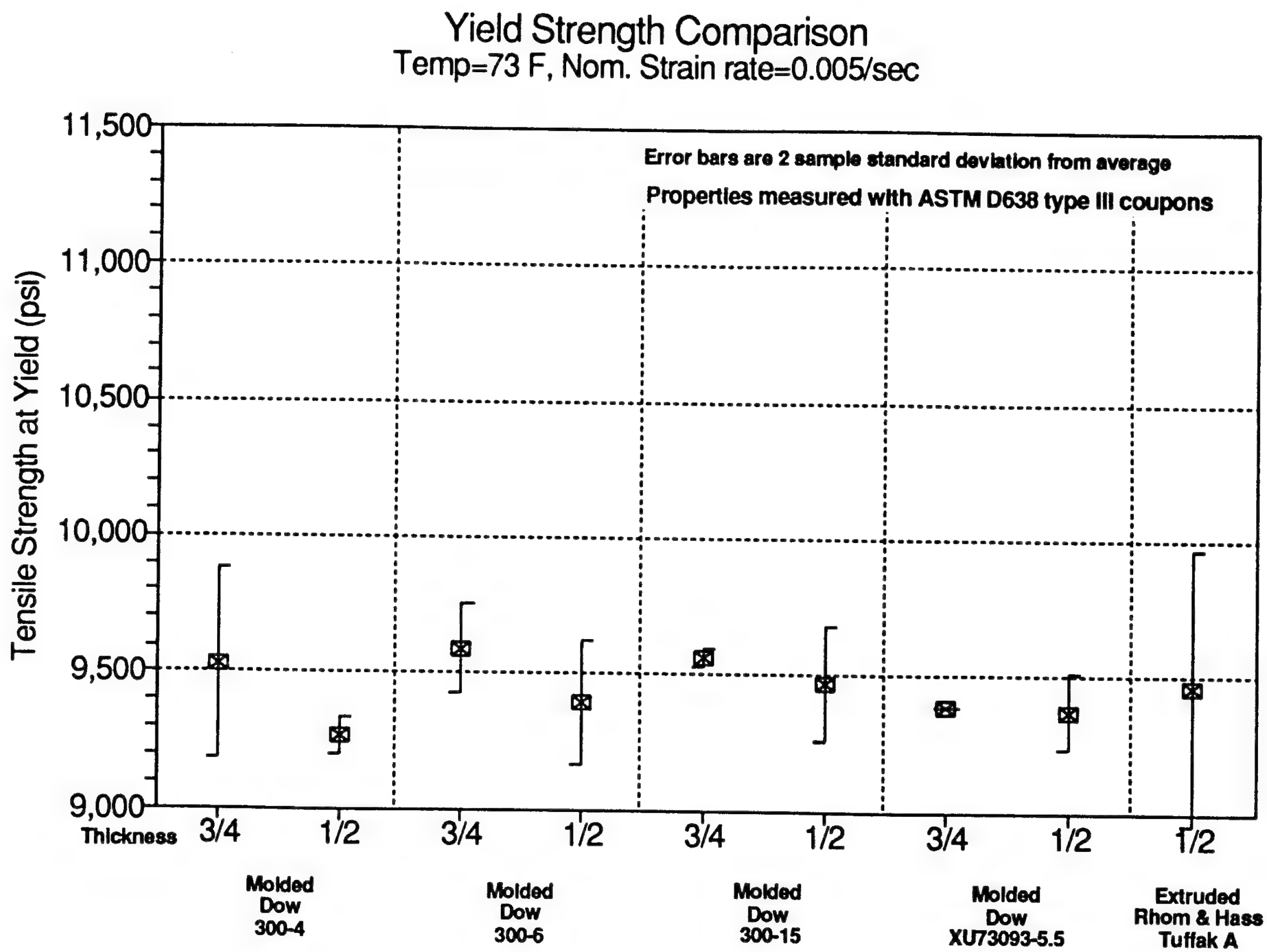


Figure 82. Flat Panel Tensile Properties Comparison - Yield Strength at 0.005/sec Nominal Strain Rate.

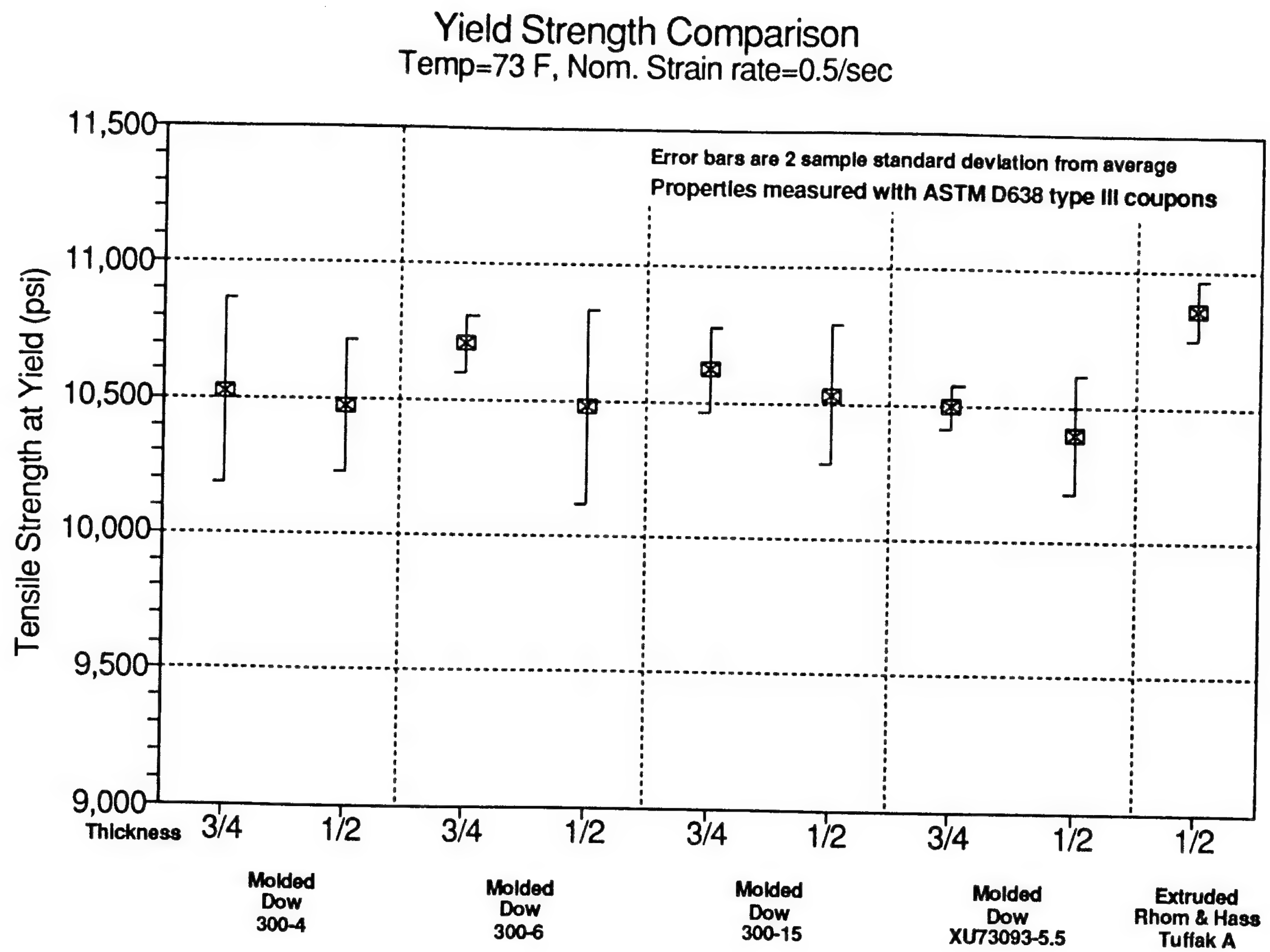


Figure 83. Flat Panel Tensile Properties Comparison - Yield Strength at 0.5/sec Nominal Strain Rate.

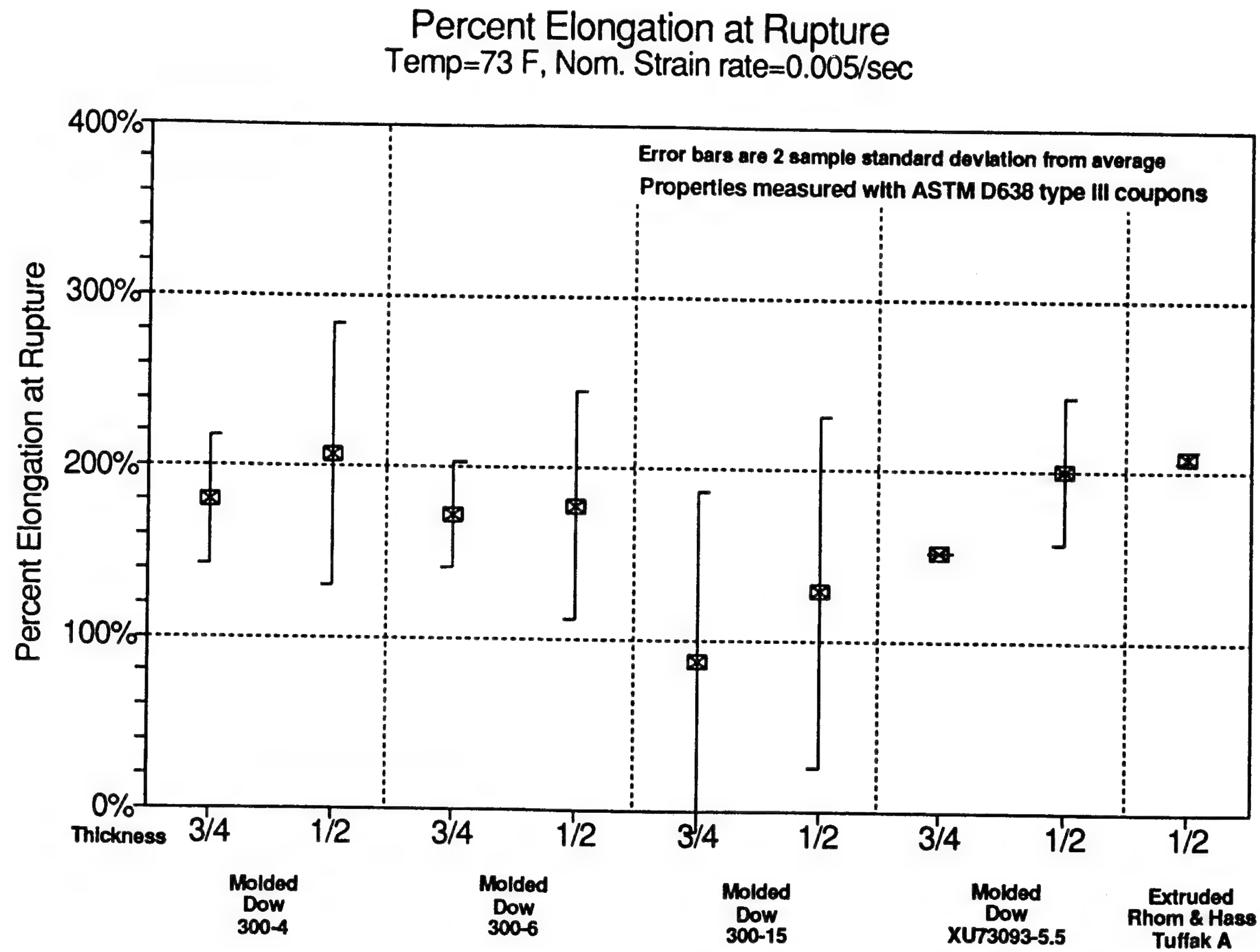


Figure 84. Flat Panel Tensile Properties Comparison - Elongation at Rupture at 0.005/sec Nominal Strain Rate.

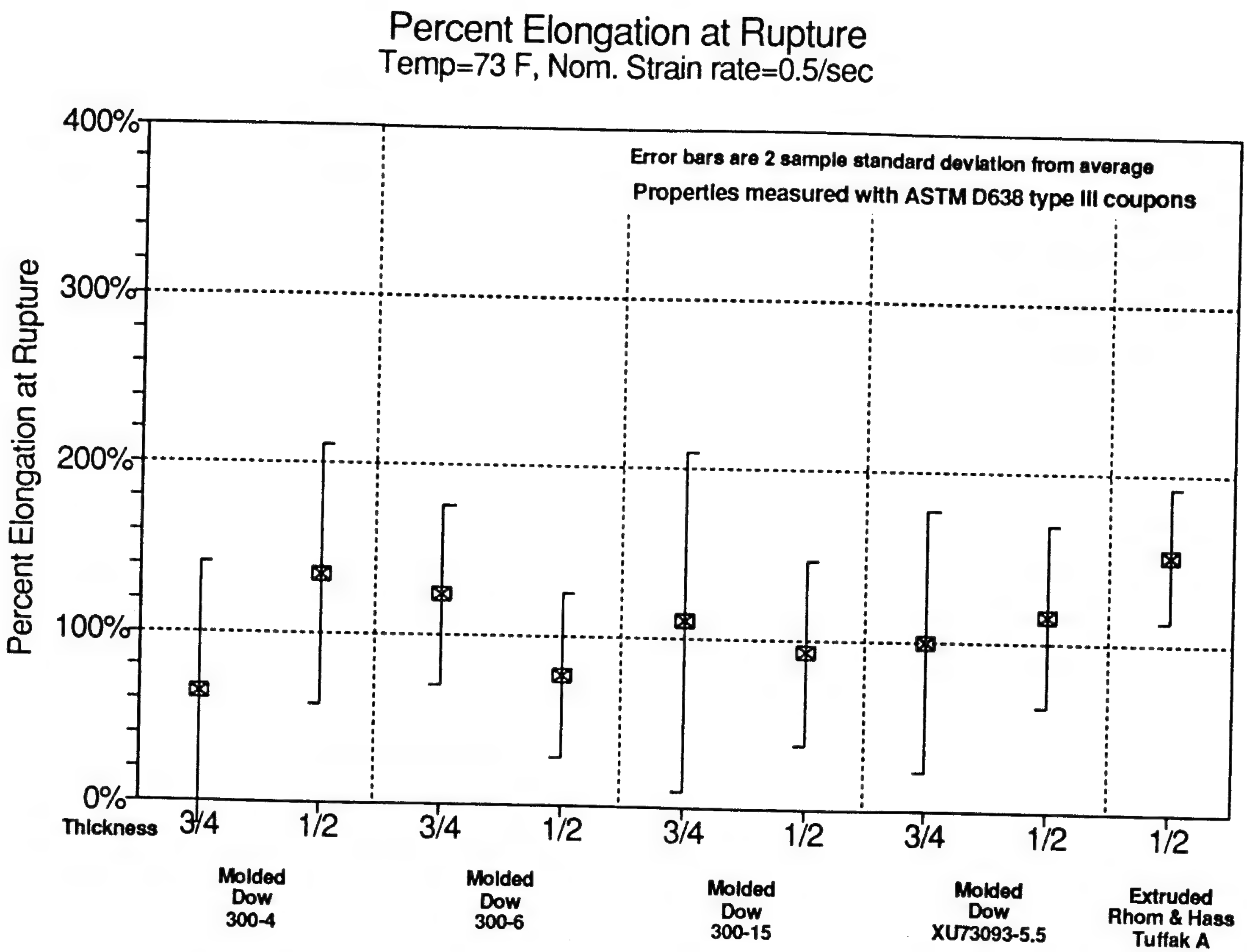


Figure 85. Flat Panel Tensile Properties Comparison - Elongation at Rupture at 0.5/sec Nominal Strain Rate.

there is some difference between the molding processes and/or resin formulation on the flat and conical panels. Finally, for all of the tests, the yield strengths of the 3/4-inch panels are higher than those for the 1/2-inch panels. It is not known whether this indicates a difference in the materials or is simply a result of the increased thickness of the coupon.

The elongation at rupture is also the same (within the large amount of scatter in the data) for all three MFIs at the higher rate but shows a decreasing trend with increasing MFI at the lower rate. The elongations at rupture are lower for the ASTM specimens than they are for the mini-tensile rod specimens. This is most likely due to the larger volume and surface area of the ASTM specimens than the mini-tensile rod specimens, which allows for a higher probability of flaws which can serve as sites for failure initiation. On average the elongation at rupture is lower for the 3/4-inch thick panels than for the 1/2-inch panels. This also may be a function of the increased volume and surface area of the coupons from the thicker panels.

The as-measured data typically consisted of 2,000-4,000 points. A filtering program which smoothed the measured data and interpolated engineering stress and transverse strain to a set of preselected axial strain locations was used on the data for each coupon. This reduced the data required to represent each curve to about 200 points and allowed averages and standard deviations of the stress and transverse strain to be computed at each axial strain location from all coupons of the same resin, panel thickness, and strain rate. The filtered sets of data will be archived as part of a database of processing information being developed under another portion of the FTP. Average engineering stress-strain curves generated in this manner for Dow 300-6 are shown as Figures 86 and 87 for the 3/4-inch and 1/2-inch panels, respectively. Similar figures are shown for all of the resins and panel thicknesses in Appendix E, Figures 110 through 118.

True stress and true strain data were calculated using the equations listed in Section 5.1. True stress and strain data were computed only from the average engineering values determined by the procedure described in the preceding paragraph. True stress-strain curves up to the yield point for Dow 300-6 are shown as Figures 88 and 89 for the 3/4-inch and 1/2-inch panels, respectively. Similar figures are shown for all of the resins and panel

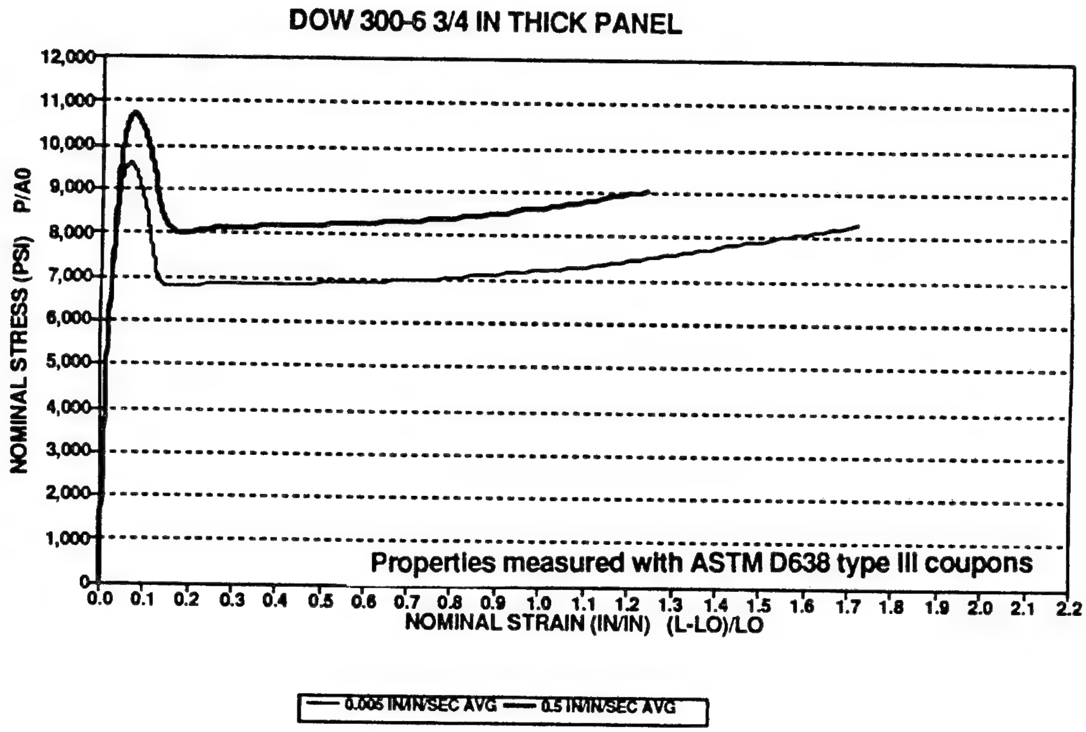


Figure 86. Average Engineering Stress-Strain Curves from 3/4-Inch Thick Flat Panels of Dow 300-6.

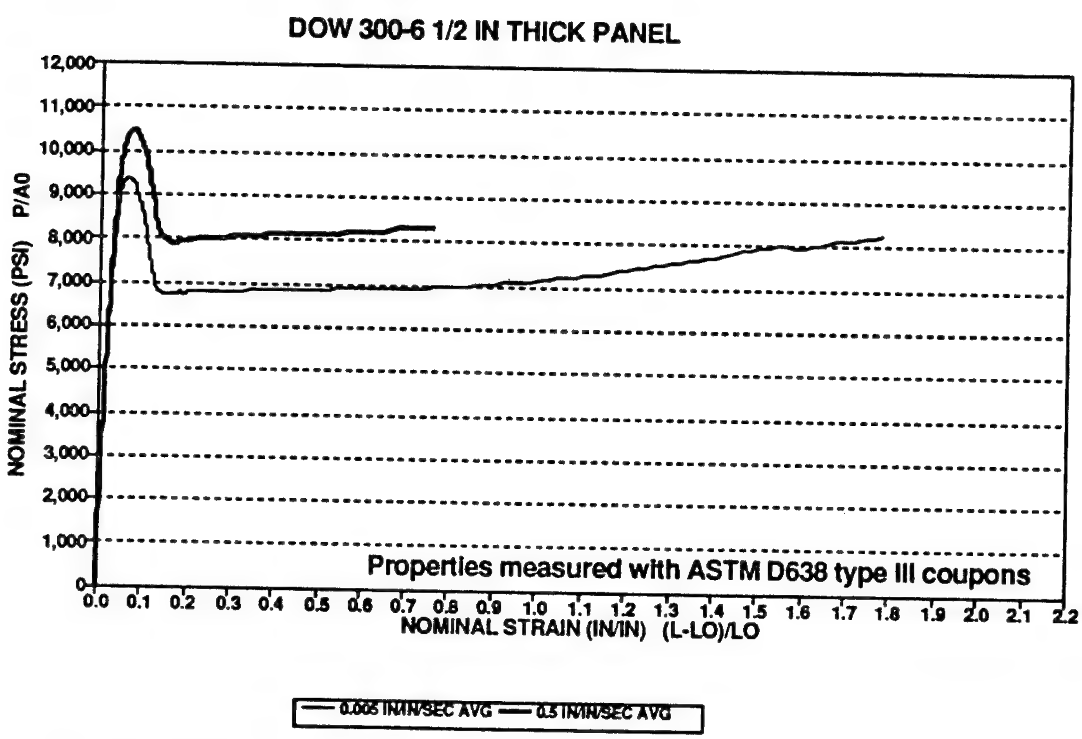


Figure 87. Average Engineering Stress-Strain Curves from 1/2-Inch Thick Flat Panels of Dow 300-6.

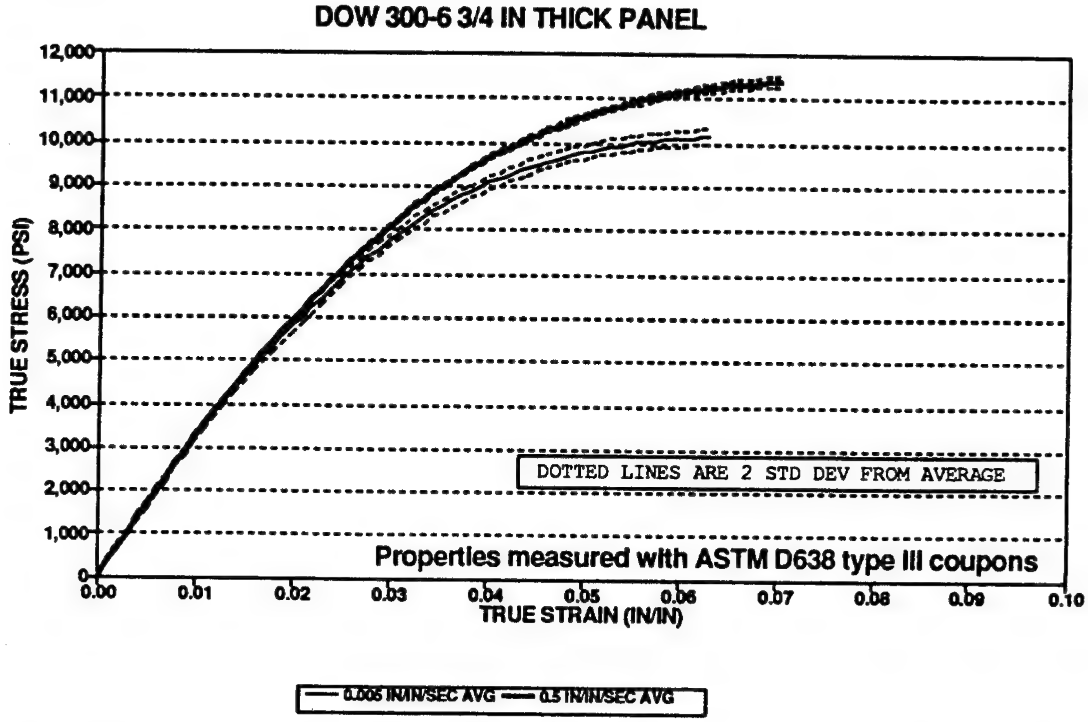


Figure 88. Average True Stress-Strain Curves from 3/4-Inch Thick Flat Panels of Dow 300-6.

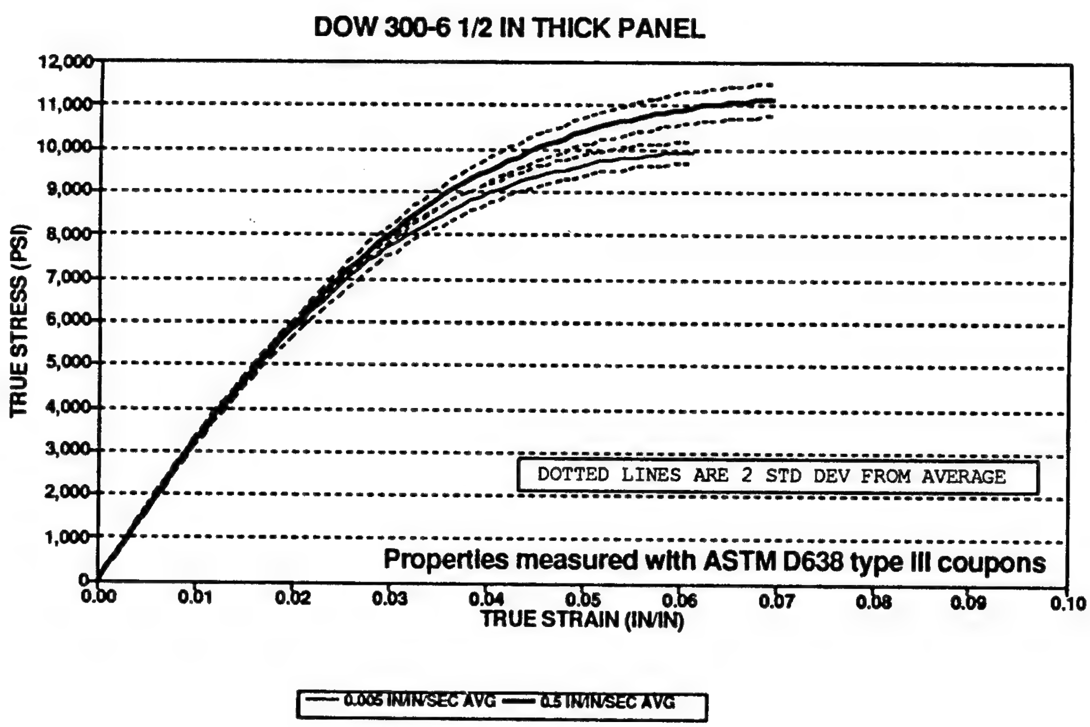


Figure 89. Average True Stress-Strain Curves from 1/2-Inch Thick Flat Panels of Dow 300-6.

thicknesses in Appendix E, Figures 119 through 127. The figures show both average stresses and 95th percentile standard deviation curves as a function of strain. From these curves for each material, true stress and strain at yield were identified. These values are listed in Table 23. Also listed are estimates of true stress and strain at failure, determined using Equations 5.7 and 5.8. These values show the same trends as the engineering stress and strain data.

Least squares fits to the true stress-axial strain and transverse strain-axial strain curves up to the yield point were used to identify coefficients as in Equations 5.9 and 5.10. These also are listed in Table 23. Although some fairly large variations occur in the coefficients of the quadratic and cubic terms, the curves computed with these cubic equations are very consistent from resin to resin at a given strain rate. Figure 90 shows Poisson's ratio and transverse strain curves which are based on averages of all of the Dow resins at each strain rate. Figure 91 shows tangent modulus and true stress curves which are averages of all of the Dow resins at each strain rate. Coefficients listed for each of the individual resin/panel thickness combinations give curves which are very close to those shown in either figure.

Overall, the engineering properties measured on the coupons from the flat panels confirm the conclusion obtained from the mini-tensile rod coupons: the small differences among the three Dow 300-xx resins tested should not significantly affect the performance of components manufactured from any of these resins. The measurements also indicate that there are some differences between the as-molded properties of the flat panels and those of the conical panels.

Table 23. Summary of True Stress-Strain Properties Measured with Flat Panel Coupons.

MATERIAL	PANEL THICKNESS (in)	NOMINAL STRAIN RATE (1/sec)	TRANSVERSE STRAIN* VS TRUE AXIAL STRAIN B1	B2	B3	TRUE STRESS* VS TRUE AXIAL STRAIN C1 (psi)	C2 (psi)	C3 (psi)	TRUE STRESS AT YIELD (psi)	TRUE STRAIN AT YIELD	TRUE STRESS AT FAILURE (psi)	TRUE STRAIN AT FAILURE
INJECTION	0.75	0.005	-0.3858	-0.5324	-6.3169	3.7811e+05	-4.3646e+06	1.5047e+07	10,100	0.062	16,600	1.03
MOLDED	0.50	0.005	-0.3769	-1.3316	1.9929	3.7205e+05	-4.2488e+06	1.3127e+07	9,820	0.063	19,400	1.12
DOW	0.75	0.5	-0.3709	-1.0410	1.7521	3.7116e+05	-3.6509e+06	9.3121e+06	11,210	0.071	15,400	0.49
300-4	0.50	0.5	-0.3742	-0.9556	0.3339	3.7511e+05	-3.8087e+06	1.0500e+07	11,400	0.070	19,100	0.85
INJECTION	0.75	0.005	-0.3765	-0.9707	-1.6487	3.6979e+05	-3.9305e+06	9.8978e+06	10,160	0.063	16,100	1.00
MOLDED	0.50	0.005	-0.3725	-1.3634	1.6596	3.7695e+05	-4.2562e+06	1.2500e+07	9,930	0.061	16,800	1.02
DOW	0.75	0.5	-0.3732	-0.9053	0.0838	3.7413e+05	-3.6407e+06	9.0315e+06	11,400	0.070	18,400	0.80
300-6	0.50	0.5	-0.3701	-0.8104	-1.2804	3.7661e+05	-3.8444e+06	1.0738e+07	11,140	0.069	15,600	0.57
INJECTION	0.75	0.005	-0.3695	-0.9628	-1.7025	3.6200e+05	-3.5900e+06	6.1223e+06	10,100	0.062	13,500	0.63
MOLDED	0.50	0.005	-0.3721	-1.3794	2.1633	3.7975e+05	-4.1850e+06	1.0893e+07	10,010	0.060	14,600	0.82
DOW	0.75	0.5	-0.3725	-0.9309	-0.3004	3.7780e+05	-3.7109e+06	9.0255e+06	11,310	0.069	17,700	0.74
300-15	0.50	0.5	-0.3785	-0.7755	-1.6201	3.8579e+05	-3.9936e+06	1.1115e+07	10,920	0.068	16,500	0.65
INJECTION	0.75	0.005	-0.3709	-1.2074	0.0605	3.6659e+05	-3.9412e+06	9.9845e+06	9,920	0.061	15,400	0.92
MOLDED	0.50	0.005	-0.3766	-1.3436	1.6683	3.7913e+05	-4.3315e+06	1.3001e+07	9,920	0.061	18,600	1.10
DOW	0.75	0.5	-0.3725	-0.8790	-1.0159	3.7283e+05	-3.7263e+06	9.8612e+06	11,170	0.070	16,200	0.69
XU73093-5.5	0.50	0.5	-0.3766	-0.7586	-1.6973	3.8176e+05	-4.0330e+06	1.2184e+07	11,050	0.068	17,400	0.77
EXTRUDED	0.50	0.005	-0.3733	-1.1864	0.3829	3.9442e+05	-4.6434e+06	1.5965e+07	10,302	0.066	18,700	1.13
TUFFAK A	0.50	0.5	-0.3787	-0.3569	-5.1224	4.0529e+05	-4.4916e+06	1.5647e+07	11,594	0.077	17,800	0.92

* $\varepsilon^t = B1 * \varepsilon^a + B2 * (\varepsilon^a)^2 + B3 * (\varepsilon^a)^3$ and $\sigma = C1 * \varepsilon^a + C2 * (\varepsilon^a)^2 + C3 * (\varepsilon^a)^3$
where ε^t is transverse true strain, ε^a is axial true strain, and σ is true stress.

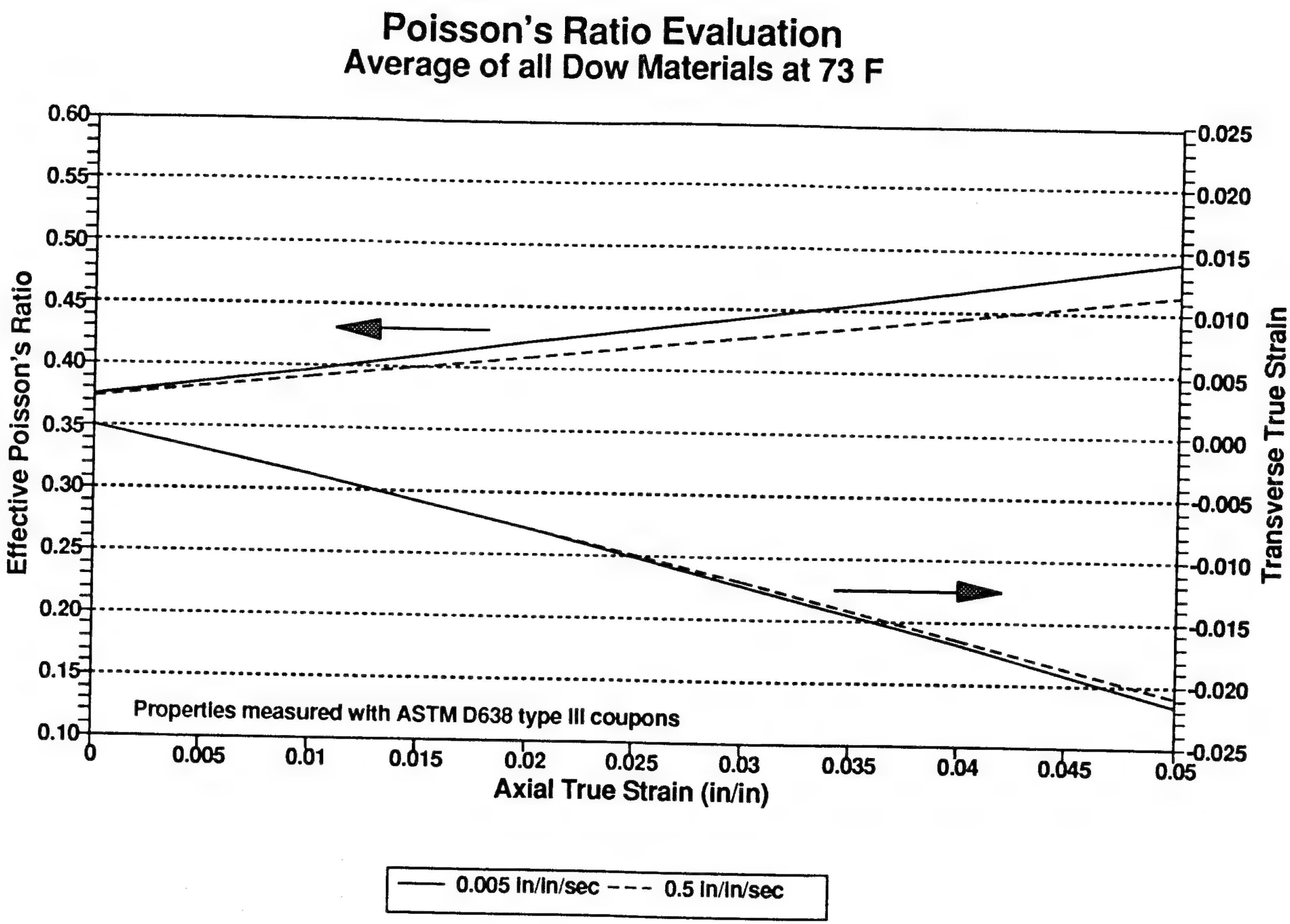


Figure 90. Change in Transverse Strain and Poisson's Ratio with Increasing Axial Strain.

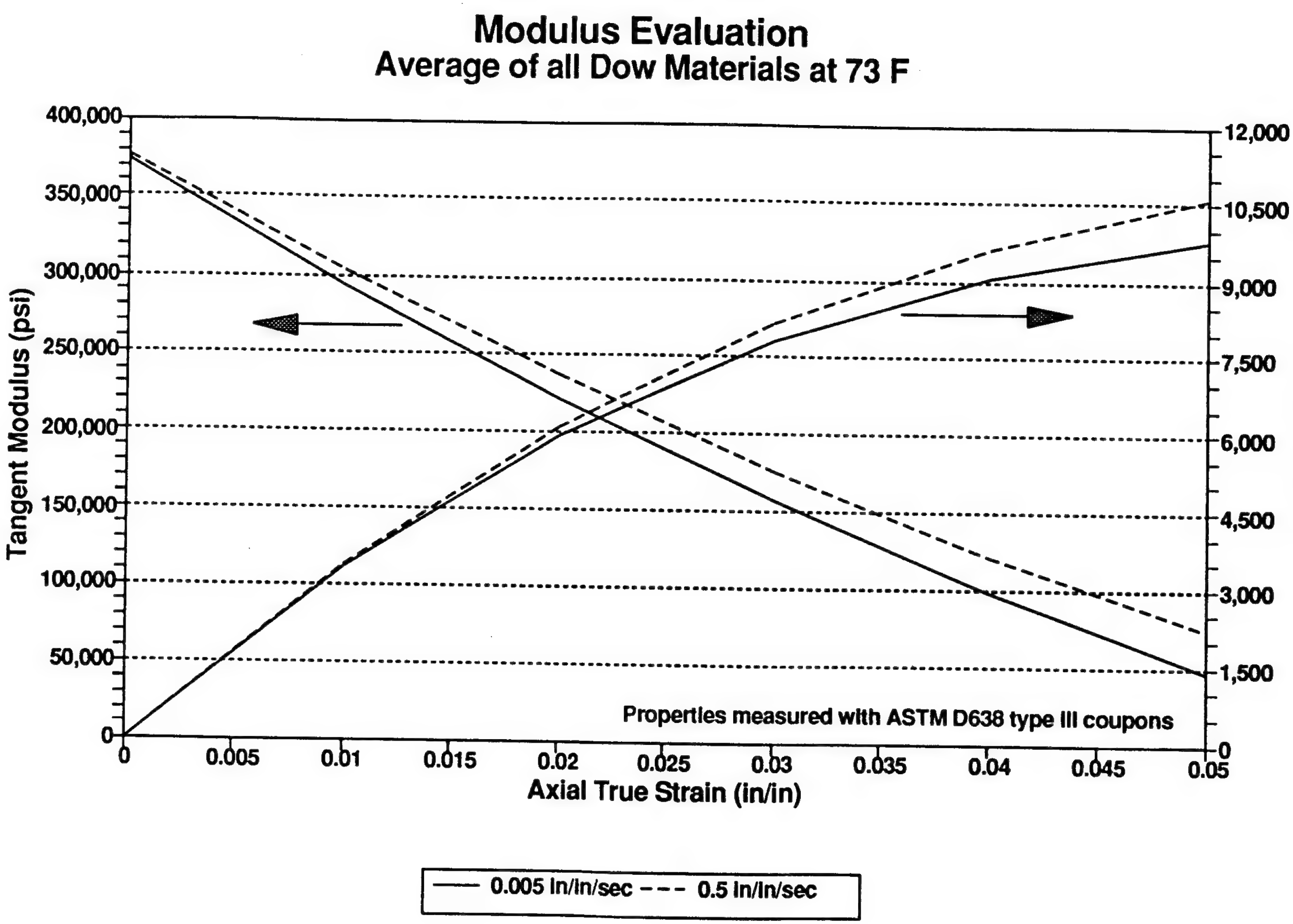


Figure 91. Change in True Stress and Tangent Modulus with Increasing Axial Strain.

SECTION 6
CONCLUSIONS

Based on the experience with molding panels and cones from the resins evaluated in this effort, the following conclusions were reached.

- Molding the range of melt flow indexes (MFIs) in the panel configurations desired presented no problems. The on-site testing did not indicate that the properties of 3/4-inch panels were degraded relative to those of 1/2-inch panels.

- As MFI changed, the molding parameters also changed. Increased MFI required that the screw speed be increased and caused the mold fill time to decrease.

- The experimental resin produced flat panels with the best appearance, but produced cones with the worst appearance. No definitive reason for this lack of consistency is known.

- As MFI decreased, edge sink (which is incomplete packing at the thickened edges of the panels) was more pronounced. The higher viscosity associated with lower MFI resins may have prevented the panels from packing completely.

- On-site falling dart impact tests of a limited number of samples indicated that as MFI increased, impact resistance decreased. It should be noted that only a few coupons actually failed. Impact tests at energies higher than those used in this study should be performed to validate this conclusion.

- The 3/4-inch panels demonstrated less edge sink than the 1/2-inch panels. This indicates that the edges packed better in the thicker panels, possibly because the larger volume of the 3/4-inch mold allowed a more effective packing path than the 1/2-inch mold.

As a result of the dimensional evaluation of the panels, cones, and molds, the following conclusions were reached.

- The effect of MFI on shrinkage is very small. Trends observed in shrinkage of different panel configurations were contradictory and were very small compared with the overall shrinkage of the parts.

- The results of the overall shrinkage (lengths and width) observed in the flat and conical panels shows that a shrinkage factor of 0.0065 inch/inch (for lengths and width) would apply well to any of the resins used.

- Shrinkage through the thickness of the panels was much higher than "standard" values (i.e., up to 0.062 inch/inch) and varied with location on the panels.

- Applying an overall shrinkage factor to a part design is necessary, and typical shrinkage factors can be used when considering overall length and width dimensions. However, a compensation in mold design may be necessary to obtain desired thickness results.

- Although the shrinkage varied greatly depending on distance from the gate, and slightly for differences in MFI, the resultant variation in the thickness of the panels was not great. At a given distance on the centerline from the gate, the flat panels varied in thickness by a maximum of 0.004 inch, and the conical panels varied by a maximum of 0.007 inch. This indicates that the panel molding produced repeatable parts.

As a result of the birdstrike test program, triangulation analyses, and X3D analyses, the following conclusions were reached regarding the birdstrike resistance of candidate materials for the Confirmation Frameless Transparency (CFT).

- Eighteen polycarbonate panels were birdstrike tested at UDRI. Each panel was impact tested by a 2-pound artificial bird at a 30° impact angle with an unrestrained aft edge. Approximate thresholds of the resins were 297 knots for the Dow XU73093-5.5, 256

knots for Dow 300-15, 277 knots for Dow 300-6, and 302 knots for Dow 300-4. The results indicated that there is a slight decrease in the birdstrike threshold velocity with an increase of the MFI.

- Triangulation data were successfully obtained using the Air Force triangulation program. Of the nine 3/4-inch thick panels tested, triangulation was performed on three of the panels that passed and one of the panels that failed. Triangulation results indicated that maximum panel deflections ranged from 1.0 to 1.4 inches approximately 3-5 milliseconds after impact, depending upon the resin and impact velocity. Note deflection-time-history response of the panel that failed (up to the point of failure) was similar to that of the panels which did not fail.

- An explicit finite element analysis program, X3D, was successfully employed to simulate 256 and 302 knot impacts by a 2-pound artificial bird on a Frameless Transparency Program polycarbonate panel. Results from the X3D analyses compared very well with triangulation results up to the point of rebound. Potential reasons for the divergence in the X3D and triangulation results after maximum deflection include differences in boundary conditions and material properties, especially damping characteristics, between the test and analysis. Both the two-dimensional and three-dimensional finite element analysis models were used and exhibited similar results. Results from this program indicate that X3D is a viable tool for impact simulation in support of the Frameless Transparency Program.

- Repeated failure occurrences along the right side of the panel near the aft edge indicated that a change in the test fixture clamping is necessary to effectively determine bird impact resistance limits.

As a result of the tensile test program, the following conclusions were reached regarding the properties of, and differences between, the various Dow resins.

- Tensile tests indicate that there is a slight decrease in ductility at loading rates on the order of 0.005 to 0.5 in/in/sec with increasing MFI for Dow 300-xx resins. This result agrees with the decrease in impact threshold velocity with increasing MFI observed in bird impact tests.

- Tensile tests indicate that there are some differences between the properties of the as-molded resins in the flat panels and the conical panels. The tests show that the conical panel materials have slightly lower yield strengths and higher elongations than the flat panel materials. These characteristics indicate that the bird impact resistance of the conical panels could be expected to be slightly better than that indicated by tests on the flat panels.

- The use of diametral extensometers allowed true stress and strain data to be calculated. These data will serve to help define parameters for use with new material models being developed for X3D which will improve the accuracy of bird impact predictions.

SECTION 7
RECOMMENDATIONS

As a result of the tests described in this report, it is the recommended that a Dow resin with a low melt flow index (MFI) be used for molding the Confirmation Frameless Transparency (CFT). The data indicated a slight decrease in ductility and impact resistance with increasing MFI. However, differences between the resins with MFI in the range of 4-6 were too small to provide a strong reason for selecting one resin over another. Since materials with higher MFIs are generally easier to mold with than those with lower MFIs, it is recommended that either the Dow 300-6 or XU73093-5.5 be selected. Criteria used for deciding between these two materials can be factors (such as cost or availability) outside those described in this report.

As a result of the molding and dimensional mapping, the following recommendations are made.

- A dependable method to determine the temperature of the molten resin entering the mold is required if accurate correlation between part quality and melt temperature are desired. Several methods should be considered. The availability of nonintrusive, direct, temperature sensing devices at the nozzle tip or mold sprue should be investigated. The use of thermocouple(s) directly in the melt stream at the nozzle tip or mold sprue should be considered. If neither of these methods are practical, then careful study of comparisons between purged material temperature and nozzle tip temperature should be carried out. This may provide information that will reveal a correlation between the two temperatures which could be used to extrapolate melt temperature from nozzle tip temperature.

- Instrumented measurement of mold fill time is recommended. This parameter is extremely useful in analyzing molding data, and care should be taken to get an accurate time for mold fill.

- A molding machine with a different configuration (i.e., reciprocating screw, or First In First Out (FIFO) accumulator) should be considered for future CFT and/or panel molding. The FILO arrangement of the machine used in this effort has too many opportunities for resin degradation or contamination.

- Variable mold temperature should be considered in future molding. This area of the molding process may yield favorable results, particularly in the area of surface quality and dimensional control.

- An improvement in the drop dart testing procedure is in order. A powered winch should be used to raise the dart to the desired drop height. Currently, a rope and pulley system is hand operated to raise the 67 pound dart up to 22 feet high. The advantage of a powered winch is obvious. Additionally, consideration should be given to increasing the capability of the test equipment. An increase in drop height and dart weight limits is recommended.

- More impact tests should be performed to develop more confidence in the conclusion that a higher MFI results in a lower impact resistance.

- The automation of acquiring data on molding process parameters is highly recommended. The exercise of taking data by writing it on process sheets is both laborious and prone to inaccuracy.

- A Dimensional Mapping study of the CFT mold and selected CFTs is recommended. This study will further the knowledge base required to realize the potential benefits of directly forming transparencies. Additionally, the CFT will be the first full size transparency to be directly formed. A thorough understanding of the thickness distribution of the CFTs and the CFT mold will be required.

- In future molding efforts, investigations should be accomplished to quantify the closing and seating of the separate mold halves. As of this writing, a complete study of this

subject has not been accomplished. Furthermore, during CFT molding (conducted in September, 1993, after this effort was completed) preliminary investigations on this subject showed that the mold does not necessarily close as designed.

As a result of the birdstrike and tensile test programs, the following recommendations are made regarding the birdstrike resistance of candidate materials for the CFT.

- X3D results compared favorably with triangulation data from a Dow panel up to the time of maximum deflection at which point the solutions diverge. Results from this program indicate that X3D is a viable tool for impact simulations, but that more effort is recommended to determine the cause for the solution divergence and to implement appropriate modifications.

- To perform comparative impact analyses, it is critical that high-strain rate material property data be available for each candidate material, and that updated material models be incorporated into X3D. More effort is recommended to refine the material modeling techniques in X3D and to define appropriate parameters for the material models used for the CFT.

- Two-dimensional finite element models are recommended over three-dimensional finite element models for transparency impact analyses because they result in smaller models which reduce solution time and expense and produce acceptable results.

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APPENDIX A.

TRIANGULATION ANALYSIS EXAMPLE SESSION

Once the triangulation data had been collected from the test films, a data file with azimuth and elevation data were generated for each camera. Triangulation data from the 256 knot impact on panel 920413-10 MX2049 are presented on the following page. The data for the FWD camera are raw data, whereas the data for the AFT camera are normalized data. These data, in addition to the calibration results, camera frame rates, and coordinate position data for that particular test, were input to the triangulation program. Results from the triangulation analysis were deflection-time-history data for individual points on the panel. In the example session that follows, the frame rate for each camera was 5150 frames/second. However, the tracing data were collected every four frames which permitted triangulations analysis every 0.78 ms during the birdstrike for effective frame rate of 5150/4 or 1287.5 frames/sec.

Azimuth and Elevation Data for Panel 920413-10 MX2049

Aft Camera:		Forward Camera:
785	Test Number	785
-4	Point Number	-4
13	Last Frame	13
-0.5119 1.226	AZI, ELE	0.8690 2.3621
-0.5363 1.2873		0.9189 2.3142
-0.5136 1.5176		0.9180 2.2120
-0.5170 1.6629		0.9283 2.1741
-0.5128 1.5927		0.9465 2.2252
-0.5352 1.3825		0.9568 2.3614
-0.5432 1.1170		0.9985 2.5149
-0.5238 1.0567		0.9755 2.5462
-0.5020 1.2118		0.9737 2.4712
-0.5177 1.1568		0.9813 2.4486
-0.4928 1.1465		0.9796 2.4266
-0.4934 1.0864		0.9931 2.4504
-0.4738 1.0511		0.9784 2.4770
-0.5053 0.9212		0.9715 2.5161

```
RUN

DEFLECTION-TIME DATA ANALYSIS PROGRAM
        VERSION 1.0

ENTER TEST IDENTIFICATION INFORMATION

TEST ID NUMBER? 785
DATE OF TEST  ? 9/9/92
OUTPUT COMMENT LINE ? Panel 9204136-10 MX2050
DATA FILE DRIVE  ? c:
```

TRIANGULATION PROGRAM
TEST # 785
1 DIGITIZE DATA FOR A POINT
2 NORMALIZE CAMERA DATA
3 TRIANGULATE DATA
4 PLOT DATA
5 PRINT FILE CONTENTS
6 KEYBOARD DATA ENTRY
7 QUIT PROGRAM

```
ENTER SELECTION: ? 3
TRIANGULATION MODULE

DO YOU WANT A DETAILED INTERMEDIATE RESULTS (Y,N)? y
   AFTER EACH FRAME OF INFORMATION, A TONE WILL SOUND.
   PRESS ANY KEY TO CONTINUE OUTPUT WHEN READY

ENTER CAMERA SETUP INFORMATION
FWD CAMERA:
CALIBRATION FUNCTION:
SLOPE, INTERCEPT: ? 0.0273,-0.1012
LOCATION:
X,Y,Z? 0,51,118.5
FRAME RATE (frames/sec) ? 1287.5

ARE THESE VALUES CORRECT? (Y,N) ? y
ENTER CAMERA SETUP INFORMATION
AFT CAMERA:
CALIBRATION FUNCTION:
SLOPE, INTERCEPT: ? 0.0143,-0.0743
LOCATION:
X,Y,Z? 0,142,78.625
FRAME RATE (frames/sec) ? 1287.5

ARE THESE VALUES CORRECT? (Y,N) ? y


ENTER TRANSPARENCY POINT INFORMATION
POINT I.D.? -4
POINT COORDINATES
X,Y,Z: ? 0.0625,39,46.5

ARE THESE VALUES CORRECT? (Y,N) ? y
FWD CAMERA DATA FILE: c:F785-4 ? Y,N ? y
AFT CAMERA DATA FILE: c:A785-4 ? Y,N ? y
ENTER STARTING FRAME NUMBER (IMPACT FRAME IS NUMBER ZERO)? 0
TO GET AN ECHO OF THE OUTPUT SENT TO THE PRINTER, ENTER A CNTL-P
ENTER A CARRIAGE RETURN WHEN READY TO BEGIN ?
    TRIANGULATION FOR DEFLECTION-TIME DURING BIRD IMPACT TESTING
```

TEST I.D. # 785
POINT I.D. # -4
TEST DATE 9/9/92

Panel 920413-10 MX2050

ALL DIMENSIONS ARE IN INCHES.

SET-UP CONDITIONS

	POSITION	FRAME RATE (frames/sec)
SLOW CAMERA	FWD	1288
FAST CAMERA	AFT	1288

LOCATIONS

	POINT ON TRANSPARENCY	FWD CAMERA	AFT CAMERA
X =	0.063	0.000	0.000
Y =	39.000	51.000	142.000
Z =	46.500	118.500	78.625

SET-UP DISTANCES OF POINT TO CAMERA

	FWD CAMERA	AFT CAMERA
DISTANCES		
POINT TO CAMERA	72.993	107.894
ANGLES (DEGREES)		
AZIMUTH	90.298	90.035
ELEVATION	-80.538	-17.322

SET-UP FRAME
RAW MEASUREMENTS

	FWD CAMERA	AFT CAMERA
AZIMUTH	0.869	-0.512
ELEVATION	2.362	1.227

INITIAL MAGNIFICATION CAMERA CALIBRATION FACTOR ESTIMATES (FRAME 0)

FWD CAMERA	AFT CAMERA
1.892	1.469

DEFLECTION FRAME 0 TIME FROM IMPACT 0.0000 SECONDS

RAW MEASUREMENTS

	FWD CAMERA	AFT CAMERA
AZIMUTH	0.869	-0.512
ELEVATION	2.362	1.227

CHANGE ANGLES

	FWD CAMERA	AFT CAMERA
AZIMUTH	0.000	0.000
ELEVATION	0.000	0.000

ANGLES IN DEFLECTION FRAME

	FWD CAMERA	AFT CAMERA
AZIMUTH	90.298	90.035
ELEVATION	-80.538	-17.322

POINT LOCATION IN SPACE	X	Y	Z
	0.063	39.000	46.500

UPDATED DISTANCES TO CAMERAS

	FWD CAMERA	AFT CAMERA
DISTANCES		
POINT TO CAMERA	72.993	107.893

DEFLECTION COMPONENTS

	X	Y	Z	VECTOR SUM
SINCE LAST FRAME	0.000	0.000	0.000	0.000
TOTAL SINCE IMPACT	0.000	0.000	0.000	0.000

```
DEFLECTION FRAME   1    TIME FROM IMPACT  0.0008 SECONDS
                   RAW MEASUREMENTS
                     FWD CAMERA    AFT CAMERA
   AZIMUTH             0.919         -0.536
   ELEVATION           2.314          1.287
                   CHANGE ANGLES
                     FWD CAMERA    AFT CAMERA
   AZIMUTH             0.074         -0.019
   ELEVATION          -0.071          0.047
                ANGLES IN DEFLECTION FRAME
                     FWD CAMERA    AFT CAMERA
   AZIMUTH            90.372         90.016
   ELEVATION         -80.609        -17.275
POINT LOCATION IN SPACE   X          Y          Z
                       0.028     39.113     46.628
               UPDATED DISTANCES TO CAMERAS
                     FWD CAMERA    AFT CAMERA
  DISTANCES
  POINT TO CAMERA     72.848        107.748
                          DEFLECTION COMPONENTS
                        X          Y          Z      VECTOR SUM
 SINCE LAST FRAME     -0.034     0.113      0.128      0.174
 TOTAL SINCE IMPACT   -0.034     0.113      0.128      0.174
```

```
DEFLECTION FRAME   2    TIME FROM IMPACT  0.0016 SECONDS
                   RAW MEASUREMENTS
                     FWD CAMERA    AFT CAMERA
   AZIMUTH             0.918         -0.514
   ELEVATION           2.212          1.518
                   CHANGE ANGLES
                     FWD CAMERA    AFT CAMERA
   AZIMUTH            -0.001          0.018
   ELEVATION          -0.151          0.180
                ANGLES IN DEFLECTION FRAME
                     FWD CAMERA    AFT CAMERA
   AZIMUTH            90.371         90.033
   ELEVATION         -80.760        -17.096
POINT LOCATION IN SPACE   X          Y          Z
                       0.060     39.378     47.063
               UPDATED DISTANCES TO CAMERAS
                     FWD CAMERA    AFT CAMERA
  DISTANCES
  POINT TO CAMERA     72.376        107.366
                          DEFLECTION COMPONENTS
                        X          Y          Z      VECTOR SUM
 SINCE LAST FRAME      0.032     0.266      0.435      0.510
 TOTAL SINCE IMPACT   -0.003     0.378      0.563      0.678
```

.
.   OUTPUT DATA SIMILAR FOR FRAMES 3-12 .
.

```
DEFLECTION FRAME   13    TIME FROM IMPACT  0.0101 SECONDS
                   RAW MEASUREMENTS
                     FWD CAMERA    AFT CAMERA
   AZIMUTH             0.972         -0.505
   ELEVATION           2.516          0.921
                   CHANGE ANGLES
                     FWD CAMERA    AFT CAMERA
   AZIMUTH            -0.010         -0.025
   ELEVATION           0.058         -0.101
                ANGLES IN DEFLECTION FRAME
```

```
                         FWD CAMERA    AFT CAMERA
       AZIMUTH            90.450        90.040
       ELEVATION         -80.310       -17.561
   POINT LOCATION IN SPACE    X           Y           Z
                            0.072      38.605      45.904
               UPDATED DISTANCES TO CAMERAS
                         FWD CAMERA    AFT CAMERA
      DISTANCES
      POINT TO CAMERA      73.647       108.449
                               DEFLECTION COMPONENTS
                            X           Y           Z      VECTOR SUM
    SINCE LAST FRAME     -0.044      -0.116      -0.237      0.268
    TOTAL SINCE IMPACT    0.010      -0.395      -0.596      0.715
 DATA TO BE STORED IN FILE c:R785-4 OKAY (Y,N) ? y
 DO YOU WANT THE CONTENTS OF THE RESULT FILE DISPLAYED(Y,N) ? y


 CONTENTS OF RESULT FILE c:R785-4


   FWD          TOTAL DEFLECTIONS
  FRAME             IN INCHES
    #        X         Y         Z       VECTOR
                                          SUM
    0      0.00      0.00      0.00      0.00
    1     -0.03      0.11      0.13      0.17
    2     -0.00      0.38      0.56      0.68
    3     -0.01      0.49      0.82      0.96
    4     -0.00      0.37      0.68      0.77
    5     -0.03      0.04      0.25      0.26
    6     -0.04     -0.34     -0.28      0.44
    7     -0.02     -0.42     -0.39      0.57
    8      0.01     -0.22     -0.09      0.24
    9     -0.01     -0.19     -0.17      0.26
   10      0.03     -0.15     -0.17      0.23
   11      0.03     -0.22     -0.28      0.36
   12      0.05     -0.28     -0.36      0.46
   13      0.01     -0.40     -0.60      0.72
<RETURN TO CONTINUE>
DO YOU WANT TO PROCESS ANOTHER POINT (Y,N) ? n

                         TRIANGULATION PROGRAM

                              TEST # 785

                   1   DIGITIZE DATA FOR A POINT
                   2   NORMALIZE CAMERA DATA
                   3   TRIANGULATE DATA
                   4   PLOT DATA
                   5   PRINT FILE CONTENTS
                   6   KEYBOARD DATA ENTRY
                   7   QUIT PROGRAM

ENTER SELECTION: ? 7
Ok
system
```

APPENDIX B.
X3D FINITE ELEMENT CODE OVERVIEW

The X3D finite element code was developed at UDRI sponsored in part by Wright Laboratory. The program has been used successfully in the simulation of hard and soft body impacts and in the analysis of high-speed loading tests on both shells and three-dimensional solids. The code is operational on the ASD computer systems at Wright-Patterson Air Force Base and is freely available to U.S Government offices and contractors. The X3D-PATRAN interface is installed and operational on several Sun and VAX computers on the base.

X3D is an explicit finite element code, which means that the dynamic equations of motion are solved by an explicit time integration procedure. Explicit integration requires relatively small time steps for stability, and so, is most useful for wave-dominated motions, including high-speed impacts. The explicit technique provides a reliable solution and permits sophisticated modeling of material response. X3D uses a central difference procedure, in which, the allowable time step is recomputed continuously during the analysis and is adjusted automatically to obtain the most efficient solution. Typically, output is generated from an X3D analysis at equally-spaced time intervals for geometry and contour plotting. X3D also produces a "trace" output file containing frequent samples of solution variables for selected points in the model.

The X3D code contains two basic types of finite elements: solids and shells. The solids may be hexahedra (eight-node bricks) or four-node tetrahedra; the plate/shell element is a four-node quadrilateral. All of the X3D elements may be generated in PATRAN and are supported for results postprocessing. In addition, X3D contains specialized features which create PATRAN command procedures for results plotting. These specialized procedures allow PATRAN to produce output graphics for models in which individual finite elements fail and are deleted (except for their mass) in the course of the solution.

Material models supported by X3D include an isotropic, elastic-plastic model with strain rate sensitivity and ultimate failure, and an orthotropic model with brittle failure modes including delamination and fiber breakage. The pressure-volume relationship for solids can be nonlinear,

described by a polynomial equation of state. For layered shells the program contains a laminate model which accounts for significant differences in stiffness between layers as they affect the bending stiffness of the shell.

The solid finite elements in X3D are essentially constant stress elements. Therefore, when failure is predicted at a stress point, the entire solid element fails. In plate/shell elements failure may occur at individual layer integration points, and the element is retained until all of its sampling points have failed. When any element fails, its stiffness characteristics are neglected for the remainder of the solution; that is, the element no longer develops internal forces. However, the mass of a failed element remains part of the solution and is attached to the nodes originally connected to the failed element.

For hard and soft body impacts, X3D accepts finite element models of both projectile and target, with a description of the potential contact surfaces between them. The required contact surface data can be generated automatically using PATRAN. The resulting interface conditions within the impact zone are handled internally as a portion of the finite element solution so that no ad hoc loading model or estimation of the impact loading region is necessary. Failure of either the projectile or the target can be handled with standard X3D material model options.

APPENDIX C.

IMPACT ANALYSIS MODEL PATRAN SESSION FILES

The PATRAN session files shown on the following pages were used to construct X3D models of both the polycarbonate panels and artificial bird. The model depicted in Figure 48 contained 1200 plate/shell elements to model the panel and 960 tetrahedral elements to model the bird. The resulting model had 1572 nodes and an initial critical time step of 2.3 μsec. The model depicted in Figure 49 contained 5376 hexahedral elements in the panel and 960 tetrahedral elements in the bird. In addition to the node and element data, the session files generated all the contact and boundary condition data required by X3D. Material properties, solution control parameters, and element thickness data for the two-dimensional panel model were generated after PATRAN execution and incorporated into the X3D input data file.

```
$ 2-Dimensional Element Model
GO
1
VIEW
1
30,-45
SET,LINES,0
SET,LABE,OFF
GR, 1,,0.000/0.000/0.000
GR, 2,,1.750/0.000/0.000
LI, 1,ARC,5(0)/1/45,2
LI, 2,ARC,5(0)/1/45,3
GR, 5,,0.667/0.667/0.000
GR, 6,,0.875/0.000/0.000
GR, 7,,0.000/0.875/0.000
LI,10,ARC,5(0)/-1/45,2
LI,11,ARC,5(0)/-1/45,8
GR,10,,0.667/-0.667/0.000
GR,11,,0.000/-0.875/0.000
LI, 3,2G,, 1, 6
LI, 4,2G,, 6, 2
LI, 5,2G,, 1, 7
LI, 6,2G,, 7, 4
LI, 7,2G,, 5, 6
LI, 8,2G,, 5, 7
LI, 9,2G,, 3, 5
LI,12,2G,, 1,11
LI,13,2G,, 9,11
LI,14,2G,, 6,10
LI,15,2G,,10,11
LI,16,2G,, 8,10
PA, 1,2L,, 3, 8
PA, 2,2L,, 2, 8
PA, 3,2L,, 1, 7
PA, 4,2L,, 3,15
PA, 5,2L,,11,15
PA, 6,2L,,10,14
HP,1T6,EXT,0/0/6.0,1T6
SET,OVERWRITE,ON
HP,1T6,ROTATE,4(0)/1/0/-90,1T6
HP,1T6,ROTATE,5(0)/1/-30,1T6
HP,1T6,TRANS,10.3317/1.2905/0.000,1T6
SET,OVERWRITE,OFF
PA,1T6,DEL
LI,1T16,DEL
GR,2T11,DEL
RENUM
1
GR,31,,  0.0000 / -0.5000 / 0.0000
GR,32,,  0.5000 / -0.5000 / 0.0000
GR,33,,  4.0000 / -0.2500 / 0.0000
GR,34,, 19.7200 / -0.2500 / 0.0000
GR,35,, 21.3790 / -0.7285 / 0.0000
GR,36,, 22.0000 / -1.2250 / 0.0000
GR,37,, 22.6070 / -1.3333 / 0.0000
GR,38,, 23.9640 / -1.1373 / 0.0000
LI,1T7,2G,,31T37,32T38
SET,OVERWRITE,ON
LI,3T7,BL,1E9/1E-6/1/1E-6,3T7
SET,OVERWRITE,OFF
PA,1T7,EXT,//12.,1T7
GF,H1T6,,3/3/9
GF,P1,, 2/25
GF,P2,, 8/25
GF,P3,,32/25
GF,P4,, 5/25
GF,P5,, 3/25
GF,P6,, 3/25
GF,P7,, 4/25
EQUIV
N
2
1
Y
CF,H1T6,TET,,1
CF,P1T7,QUAD
CF,H1T6,TRI/3/2,T11
1
1
1
1
1
1
CF,P3T7,TRI/3/1,T1
1
1
1
1
1
TRI,P3T7,REV
OPTIM
2
DF,H1,DISP,//0/0/0/0,,F1
DF,H2,DISP,//0/0/0/0,,F2
DF,H4,DISP,//0/0/0/0,,F3
DF,H5,DISP,//0/0/0/0,,F4
DF,P1T7,DISP,//0,,ED4
DF,P1  ,DISP,6(0),,ED1
1
DF,P1T7,DISP,6(0),,ED2
```

```
$ 3-Dimensional Element Model
GO
1
VI
1
23,-34
SET,OVERW,ON
SET,LABE,OFF
SET,LINES,0
GR,1
GR,2,,4
GR,3,,8
GR,4,,22
GR,5,,/-2.75
GR,6,,4/-2.25
GR,7,,8/-2.25
GR,8,,19.72/-2.25
LI,1T7,2G,,1/2/3/1/5/6/7,2/3/4/5/6/7/8
GR,9,TR,/-1.88,8
GR,10,TR,//1,9
LI,8,ARC,G9/G10/-90,8
GR,9,TR,0.374/-1.47,4
GR,10,TR,//1,9
GR,11,TR,/-1.88,9
LI,9,ARC,G9/G10/8.217,11
GR,11,,G12
LI,9,ARC,G9/G10/-90,11
GR,9,INT,,8,9
LI,9/10,BR,9,9
LI,8/11,BR,9,8
LI,10,EX,-3,9
GR,10,TR,2,4
LI,11,,/-4//G10
GR,10,INT,,10,11
LI,10/11,BR,10,10
LI,10,EX,-0.75,11
GR,13,TR,//1,10
LI,10,RO,G10/G13/90,10
GR,13,TR,/-3,4
LI,14,2G,,4,13
LI,12,EX,-2,10
GR,15,TR,//-1,14
LI,12,RO,G14/G15/-90,12
LI,13,FIL,0.5/1,12,14
GR,13,,19.72
LI,15,,/4//G9
GR,15,INT,,3,15
LI,15T20,2G,,17/18/15/13/3/2,11/9/9/8/7/6
GR,19T24,TR,/-1.5/-4,1T3/13/15/4
GR,25T30,TR,//-4,5T9/18
LI,21T26,2G,,19T24,25T30
LI,27/28,2G,,13/15,15/4
LI,29,2G,,22,23
LI,30,TR,//-4,8
PA,1T4,ED,,12/10/11/15/    13/15/9/16/
28/14/16/17/ 27/17/8/18/
PA,5T7,ED,,3/18/7/19/ 2/19/6/20/ 1/20/5/4
PA,8/9,TR,//-4,1/2
PA,10,2L,,26,25
PA,11,ED,,29/25/30/24
PA,12T14,2L,,24/23/22,23/22/21
PA,15T21,TR,//-3,8T14
HP,1/2,EXT,//-4,1/2
HP,3T7,2P,,3T7,10T14
HP,8T14,EXT,//-3,8T14
HP,15T21,EXT,//-5,15T21
PA,22/23,HP,2/3,15
PA,24,HP,3,16
PA,25/26,HP,3/1,17
PA,27,HP,3,18
PA,28,HP,1,19
GR, 101,,0.000/0.000/0.000
GR, 102,,1.750/0.000/0.000
LI, 101,ARC,5(0)/1/45,102
LI, 102,ARC,5(0)/1/45,103
GR, 105,,0.667/0.667/0.000
GR, 106,,0.875/0.000/0.000
GR, 107,,0.000/0.875/0.000
LI,110,ARC,5(0)/-1/45,102
LI,111,ARC,5(0)/-1/45,108
GR,110,,0.667/-0.667/0.000
GR,111,,0.000/-0.875/0.000
LI, 103, 2G,, 101, 106
LI, 104, 2G,, 106, 102
LI, 105, 2G,, 101, 107
LI, 106, 2G,, 107, 104
LI, 107, 2G,, 105, 106
LI, 108, 2G,, 105, 107
LI, 109, 2G,, 103, 105
LI, 112, 2G,, 101, 111
LI, 113, 2G,, 109, 111
LI, 114, 2G,, 106, 110
LI, 115, 2G,, 110, 111
LI, 116, 2G,, 108, 110
PA, 101, 2L,, 103, 108
PA, 102, 2L,, 102, 108
PA, 103, 2L,, 101, 107
PA, 104, 2L,, 103, 115
PA, 105, 2L,, 111, 115
PA, 106, 2L,, 110, 114
```

```
HP,101T106,EXT,0/0/6.0,101T106
HP,101T106,ROTATE,4(0)/1/0/-90,101T106
GR,123,TR,//1,109
HP,101T106,ROTATE,G109/G123/-30,101T10
6
HP,101T106,TRANS,9.48268/.26/-12.0,101T10
6
PA,101T106,DEL
LI,101T116,DEL
GR,102T111/123,DEL
GF,H1,,8/4/9
GF,H2,,8/4/9
GF,H3,,4/8/9
GF,H4,,8/4/9
GF,H5,,15/8/9/3//
GF,H6,,4/8/9
GF,H7,,4/8/9
GF,H8,,8/4/7
GF,H15,,8/4/11
CF,H1T8/15,HEX,,1
ME,H9T14/16T21,HEX,I,1,1
GF,H101T106,,3/3/9
CF,H101T106,TET,,2
CF,H101T106,TRI/3/2,T11
1
1
1
1
1
1
ME,P22T28,TRI/3/1,I,1
TRI,P23T28,REV
DF,H5/6,DISP,3(0),,FAC6
DF,H14/21,DISP,3(0),,FAC4
DF,H15T21,DISP,//0,,FAC6
3
DF,H101,DISP,//0,,FAC1
DF,H102,DISP,//0,,FAC2
DF,H104,DISP,//0,,FAC3
DF,H105,DISP,//0,,FAC4
EQUIV
N
2
1
Y
OPTIMIZE
2
```

APPENDIX D.

BIRDSTRIKE POSTTEST PHOTOGRAPHS

Posttest photographs for each of the 18 polycarbonate panels birdstrike tested in this program are presented in Figures 92-109. Refer to Tables 15 and 18 for a description of specific details regarding the panels or test conditions. Lines were marked on the panel with a grease pencil to outline the bird footprint. Crosses marked on the panels are for triangulation purposes.

A pattern in the failures seemed evident when the films were reviewed. Of the nine panels that failed, six failed in the clamped area along the right side of the panel near the aft edge. It appears that test results for panels with failure origins of this type may not be indicative of bird impact resistance limits. The current test fixture clamping arrangement may be inadequate.

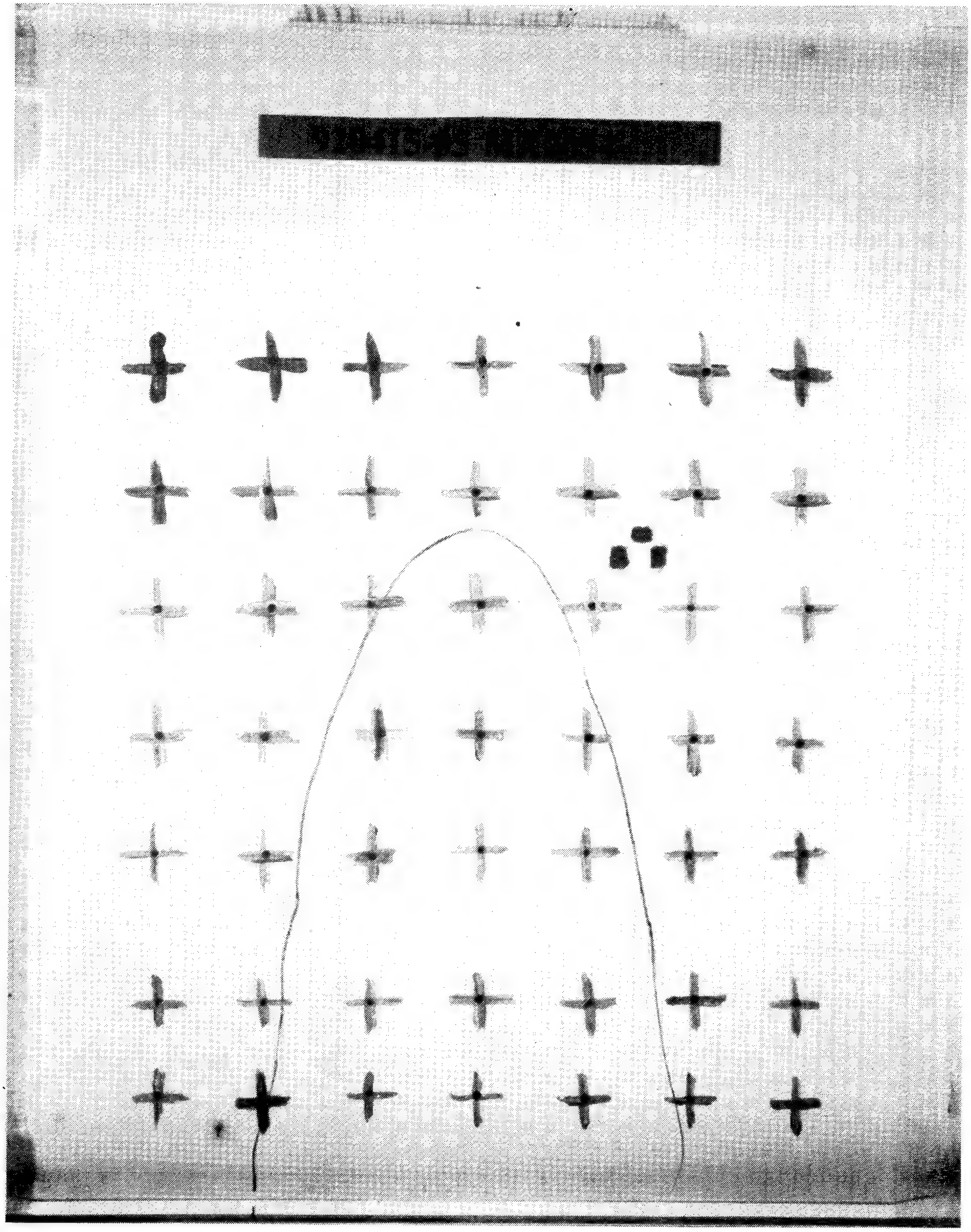

Figure 92. Posttest Photograph of Panel 920415-05 MX2054 (247 knots).

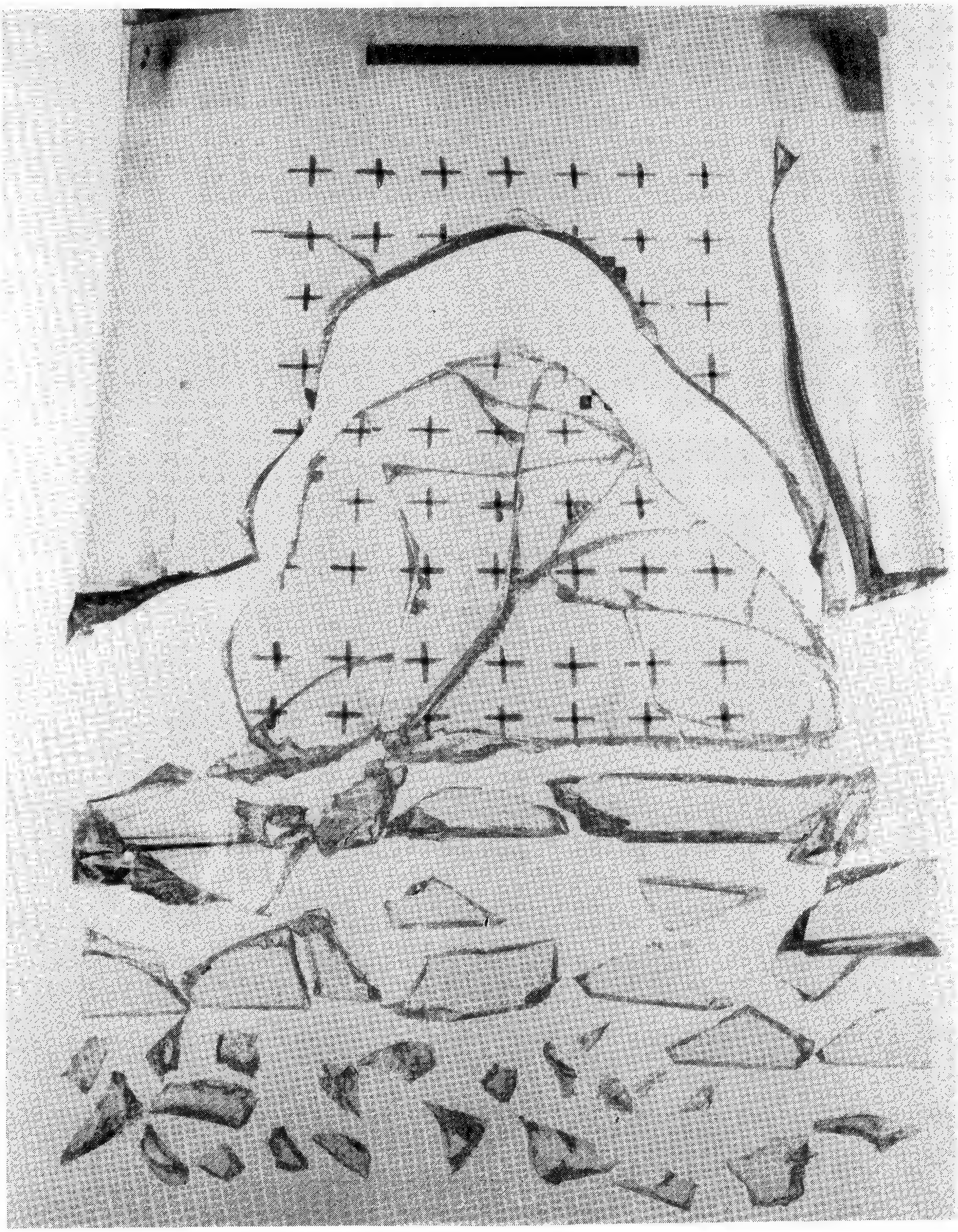

Figure 93. Posttest Photograph of Panel 920415-06 MX2054 (396 knots).

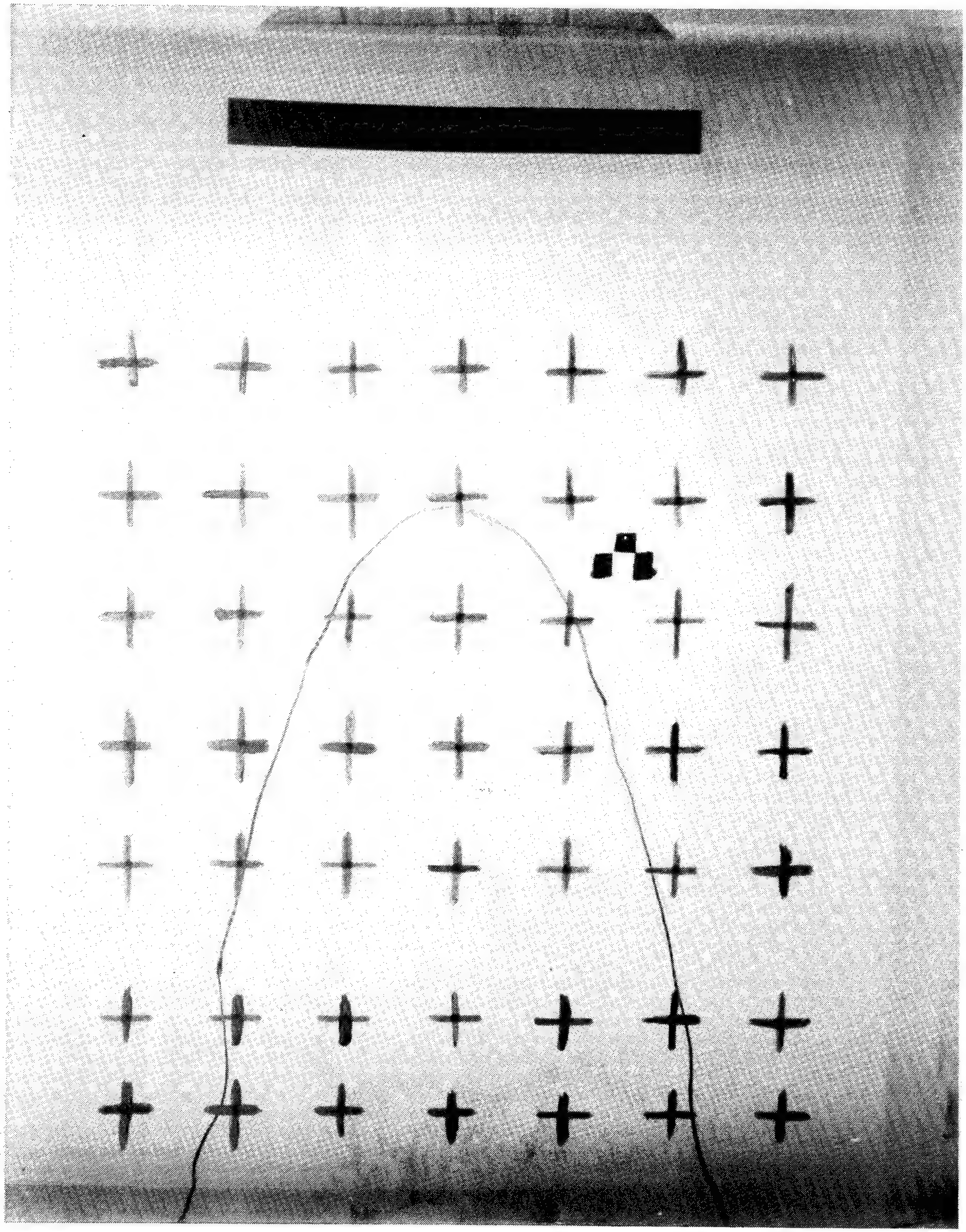

Figure 94. Posttest Photograph of Panel 920415-07 MX2054 (301 knots).

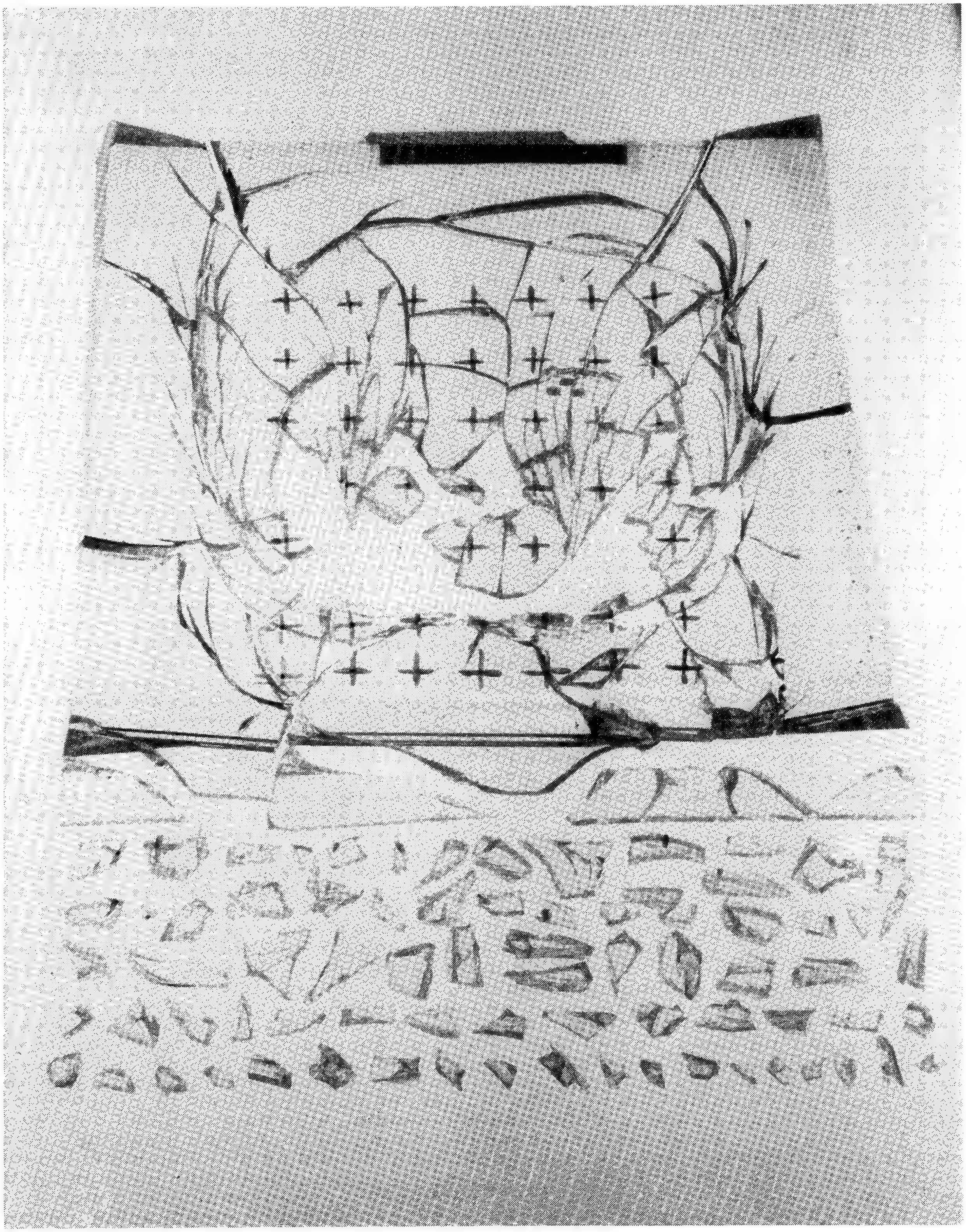

Figure 95. Posttest Photograph of Panel 920414-04 MX2053 (353 knots).

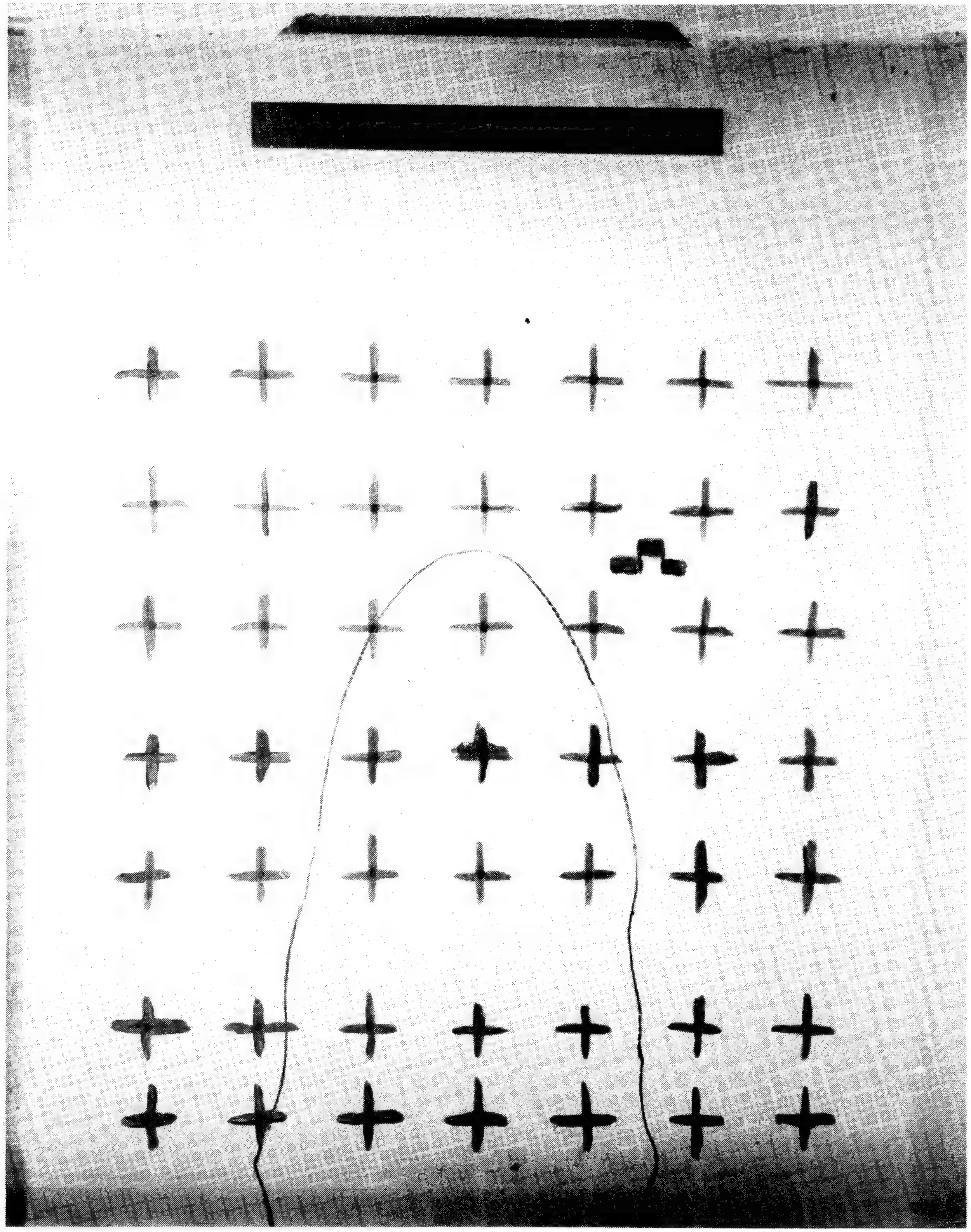

Figure 96. Posttest Photograph of Panel 920414-05 MX2053 (200 knots).

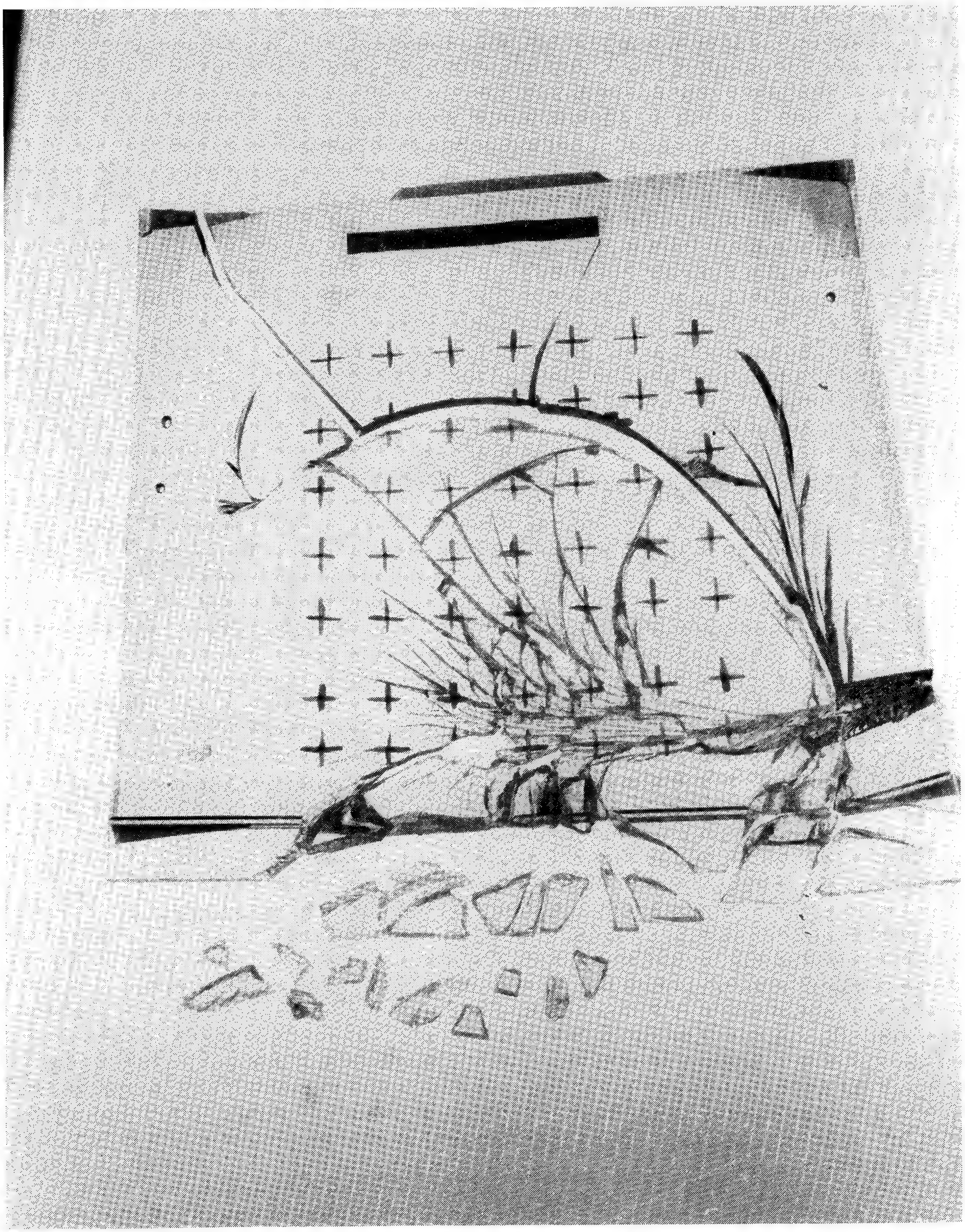

Figure 97. Posttest Photograph of Panel 920414-08 MX2053 (249 knots).

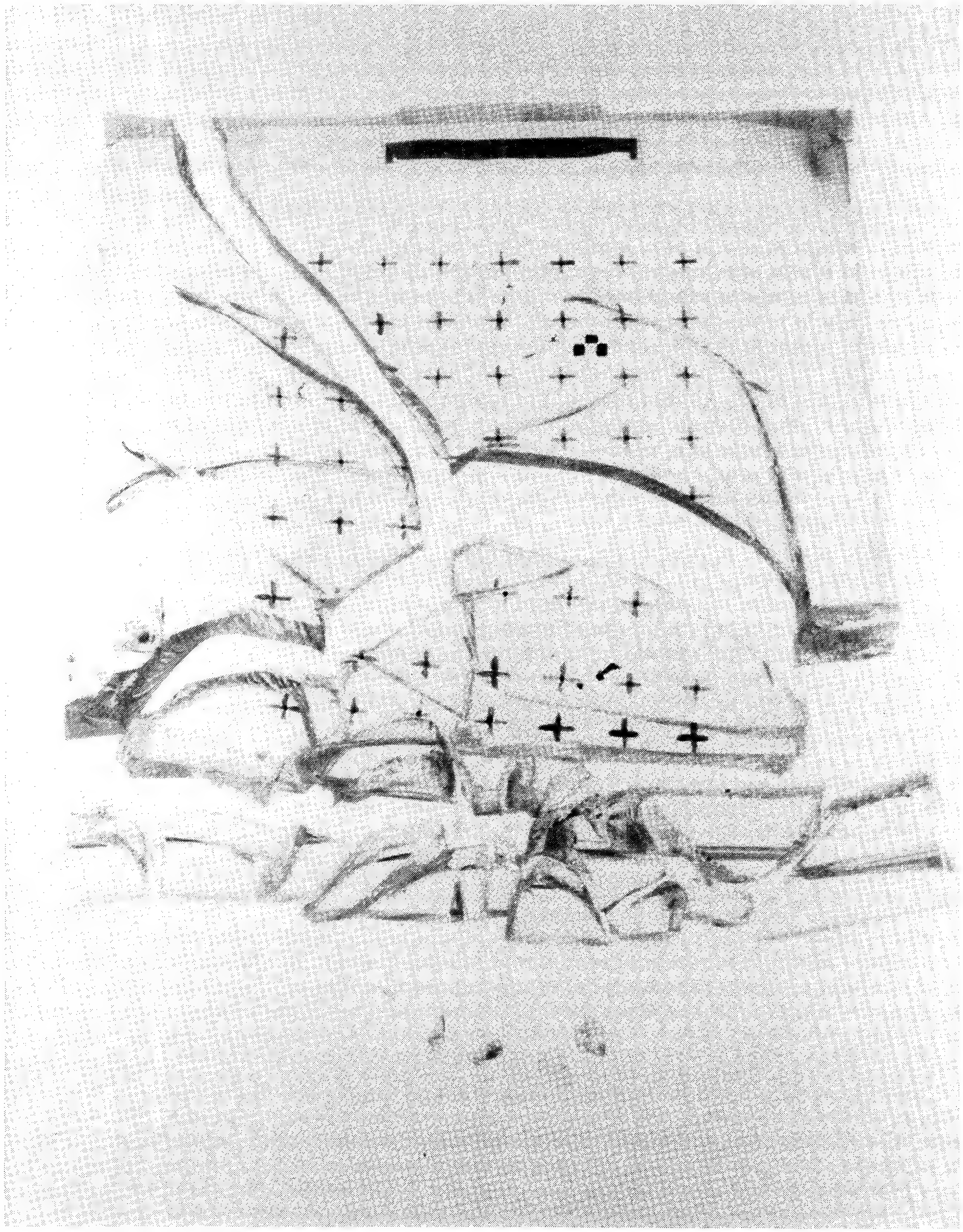

Figure 98. Posttest Photograph of Panel 920415-05 MX2050 (450 knots).

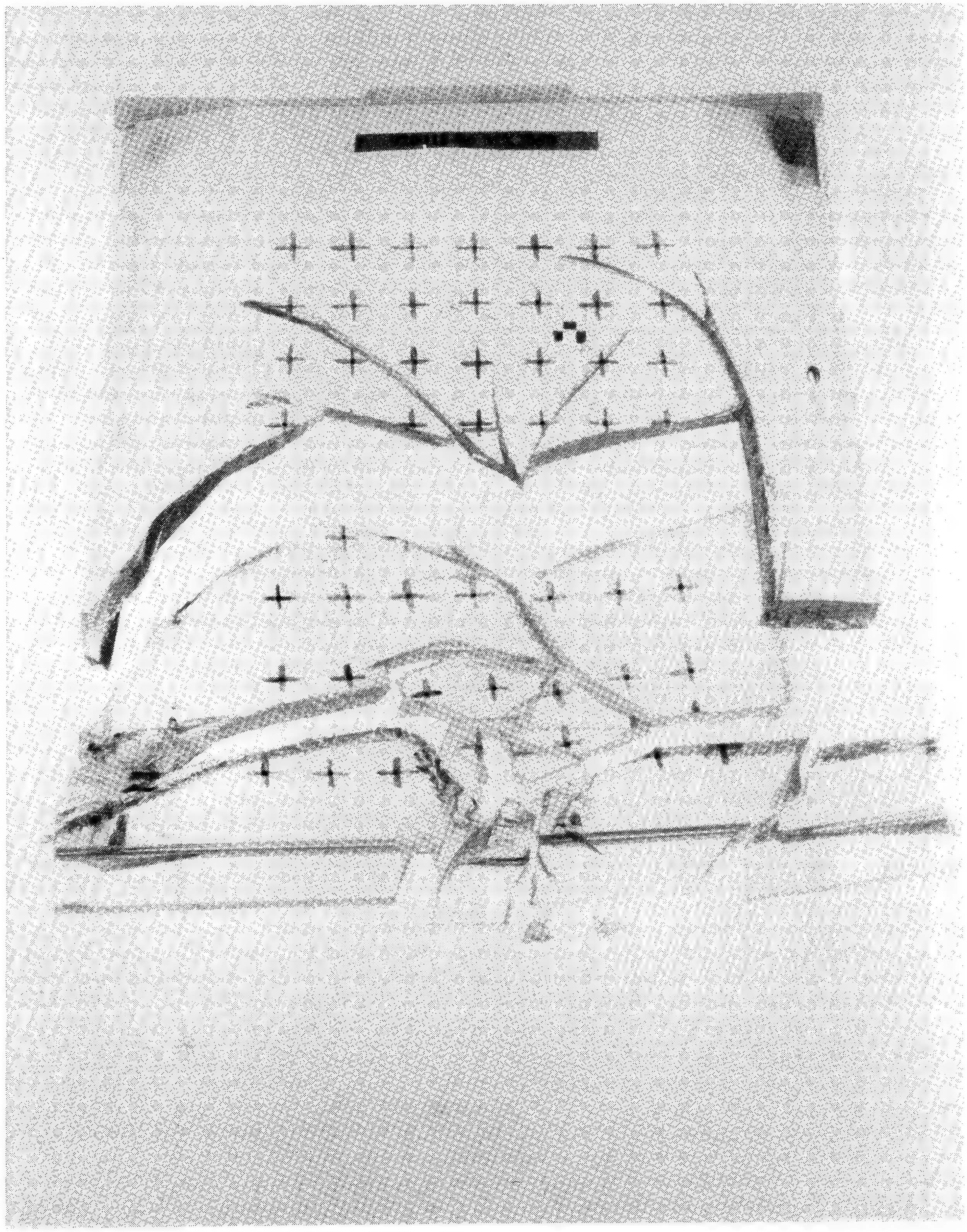

Figure 99. Posttest Photograph of Panel 920415-06 MX2050 (355 knots).

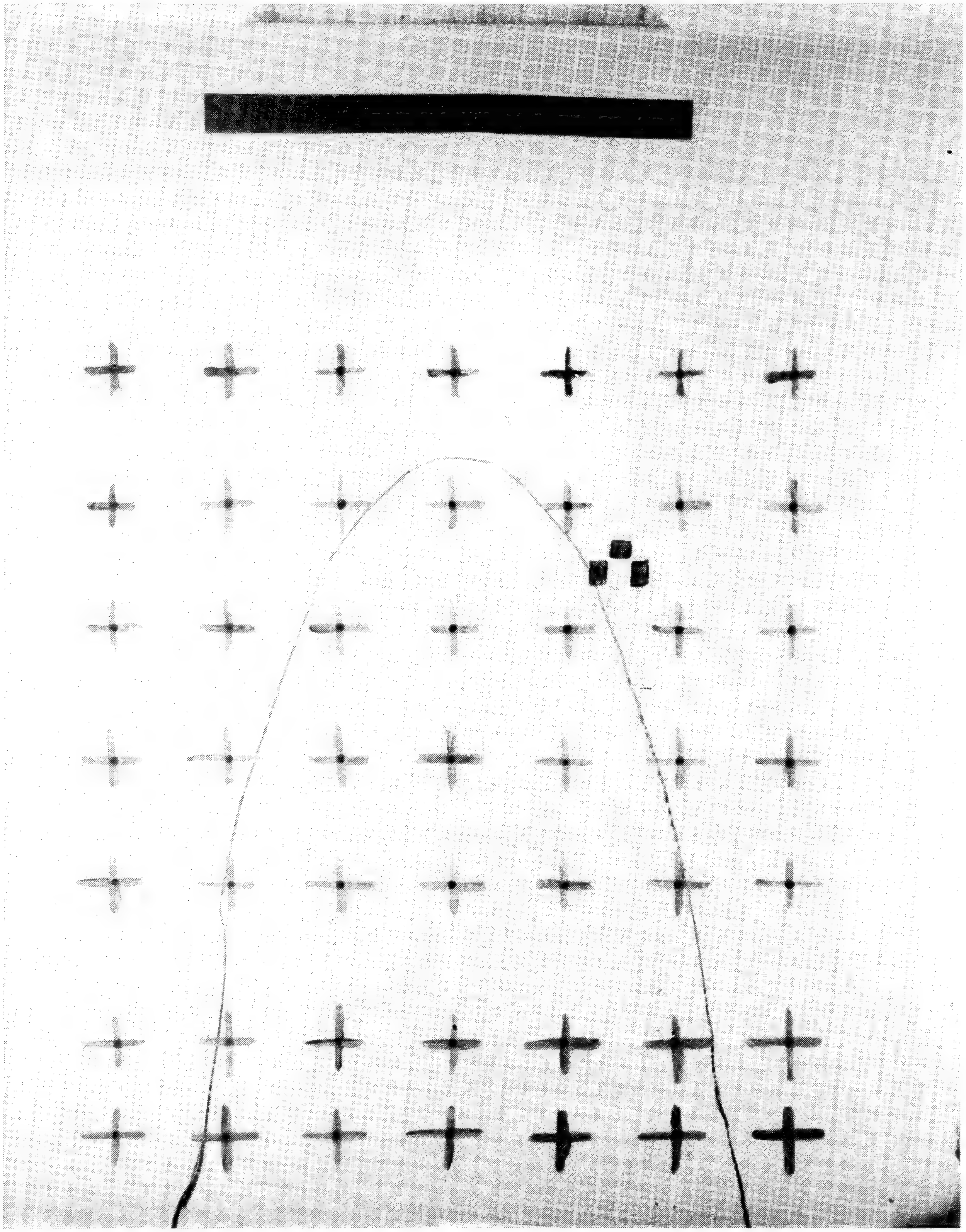

Figure 100. Posttest Photograph of Panel 920415-07 MX2050 (297 knots).

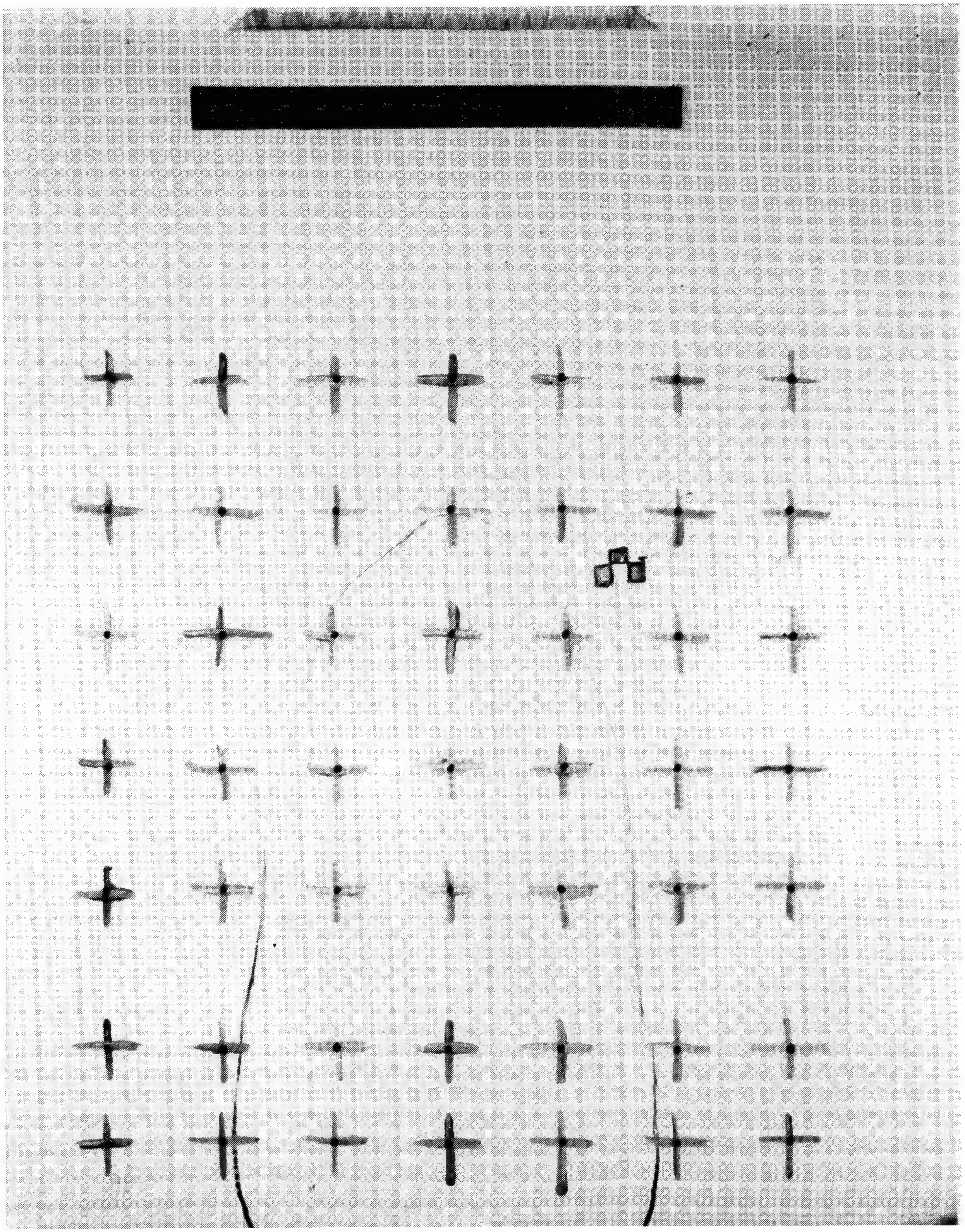

Figure 101. Posttest Photograph of Panel 920413-07 MX2049 (201 knots).

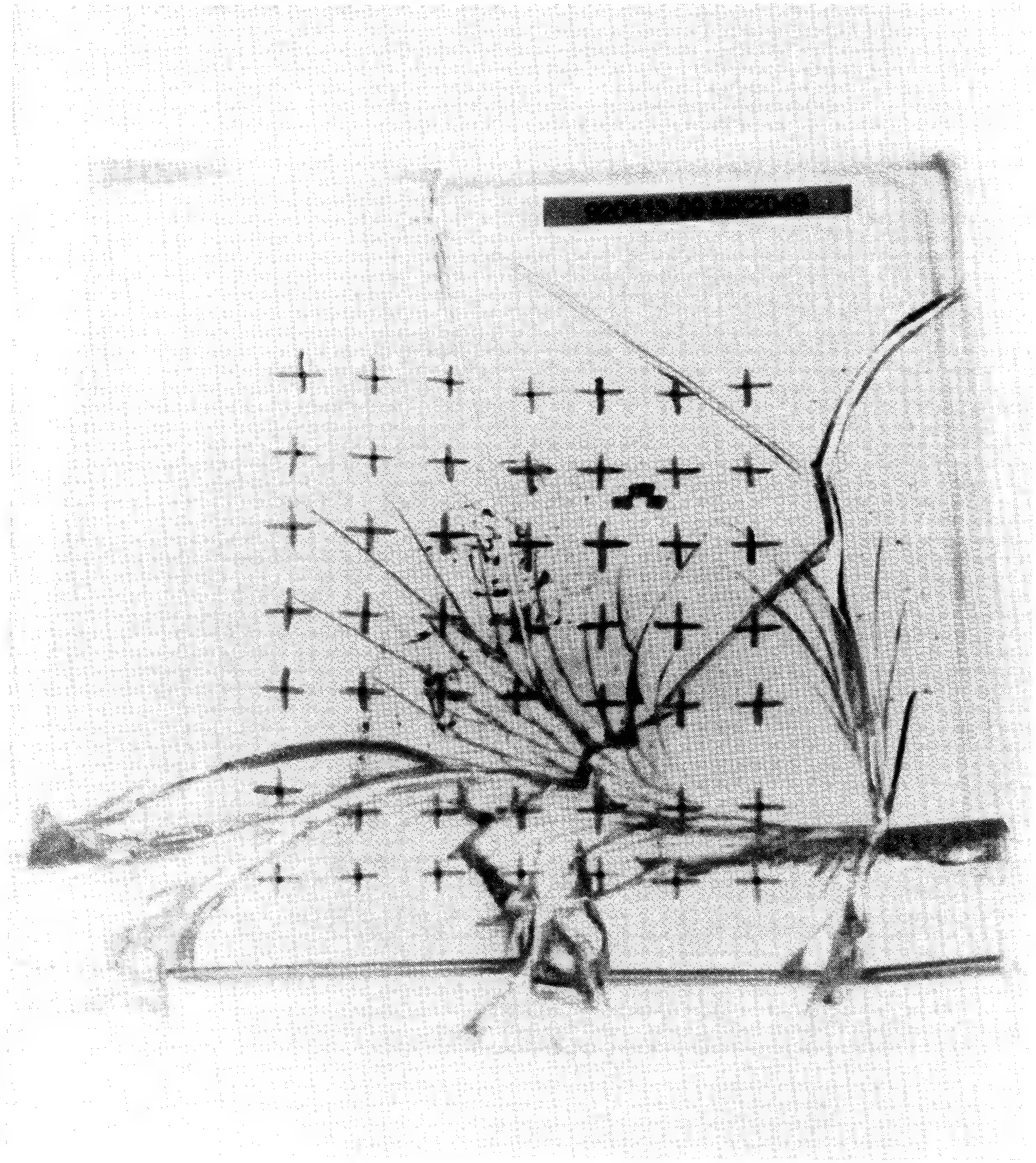

Figure 102. Posttest Photograph of Panel 920413-09 MX2049 (302 knots).

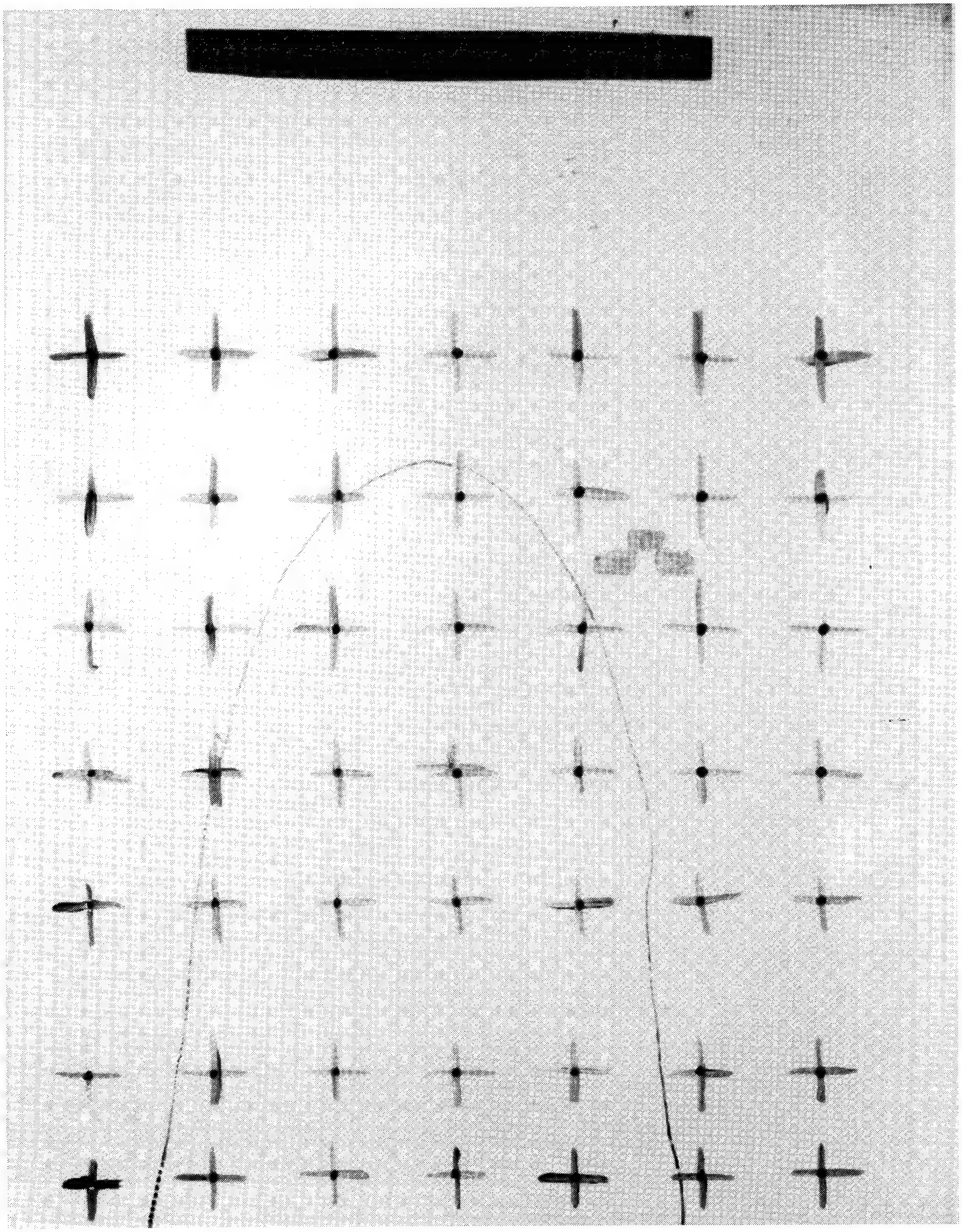

Figure 103. Posttest Photograph of Panel 920413-10 MX2049 (256 knots).

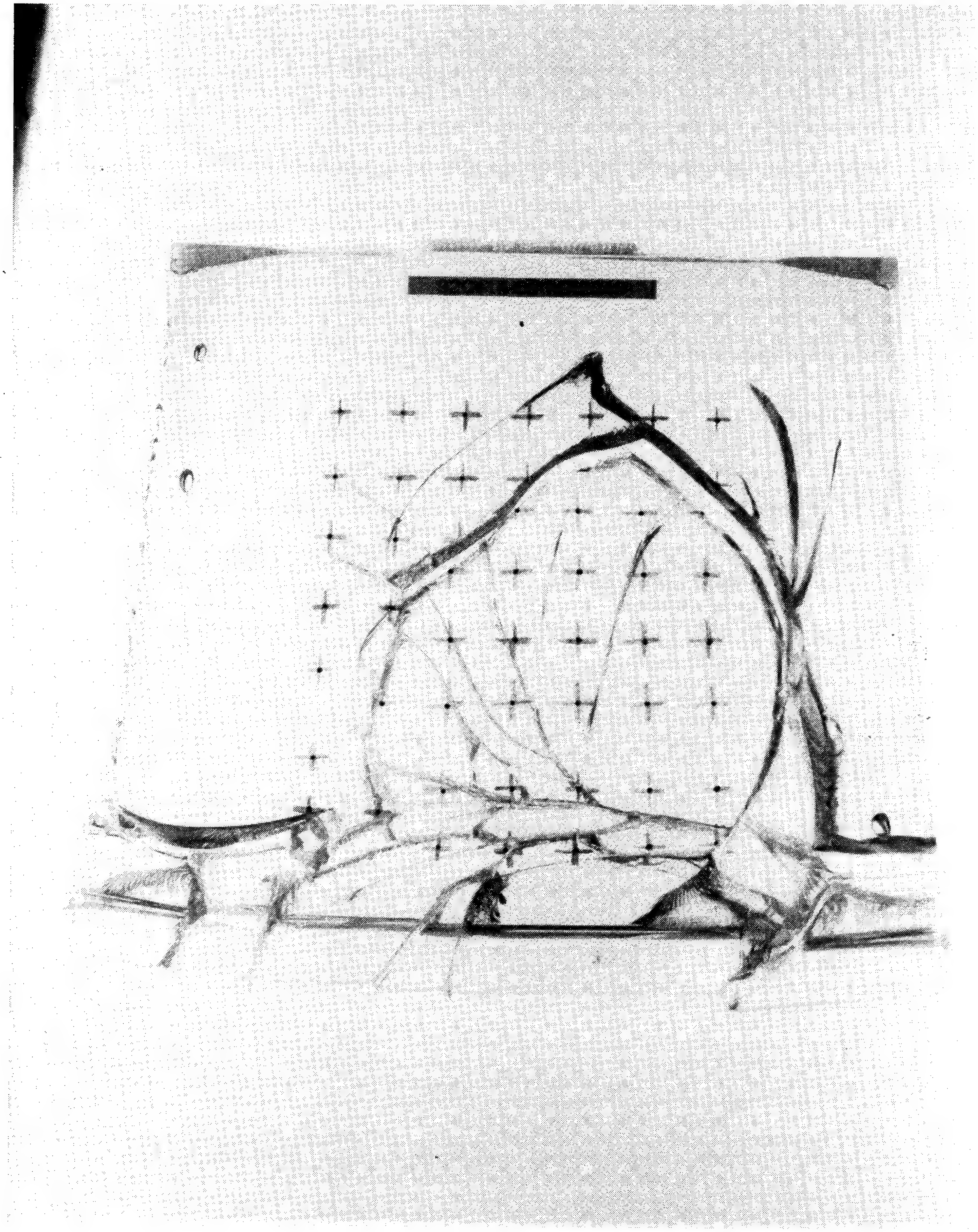

Figure 104. Posttest Photograph of Panel 920414-05 MX2048 (302 knots).

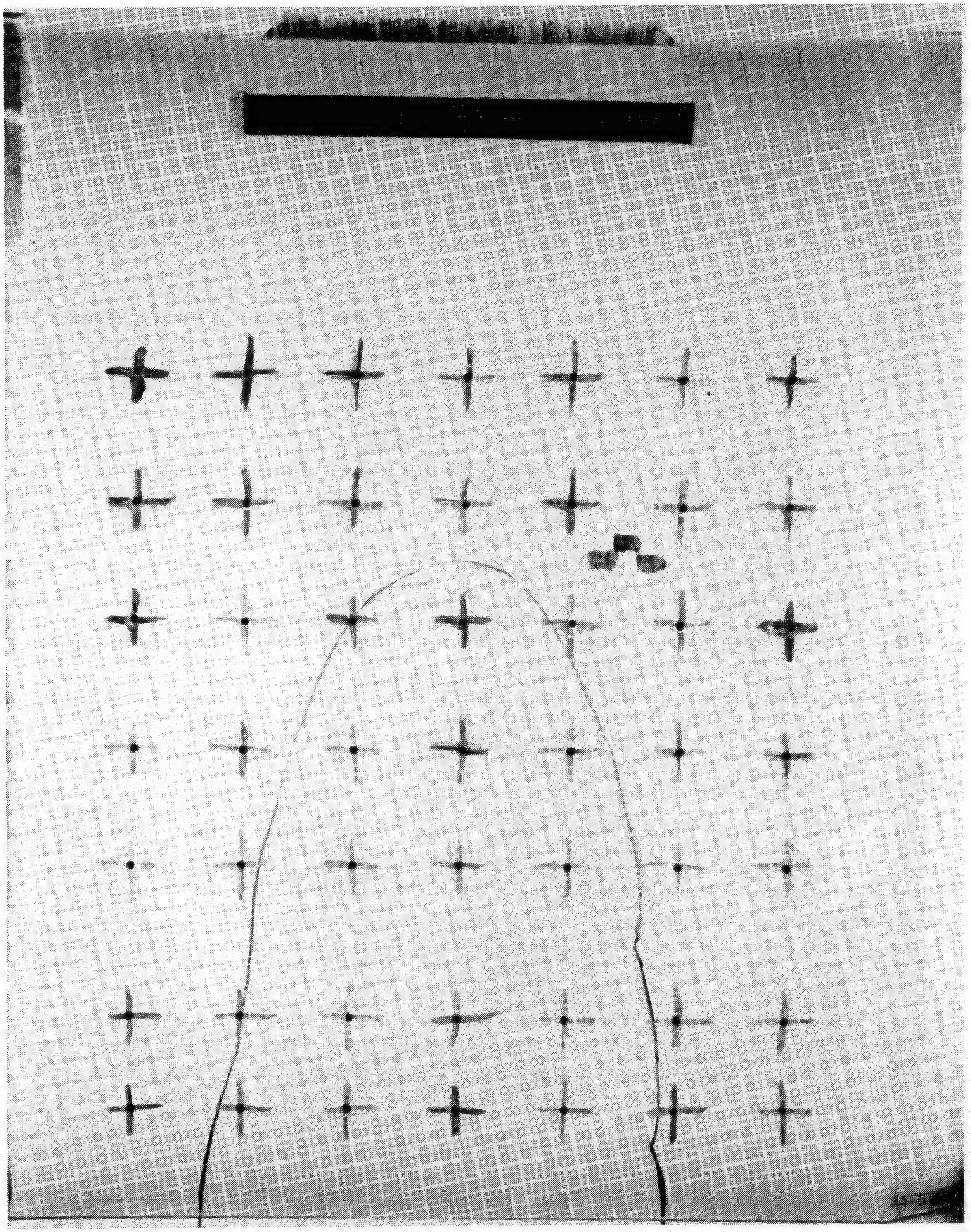

Figure 105. Posttest Photograph of Panel 920414-07 MX2048 (252 knots).

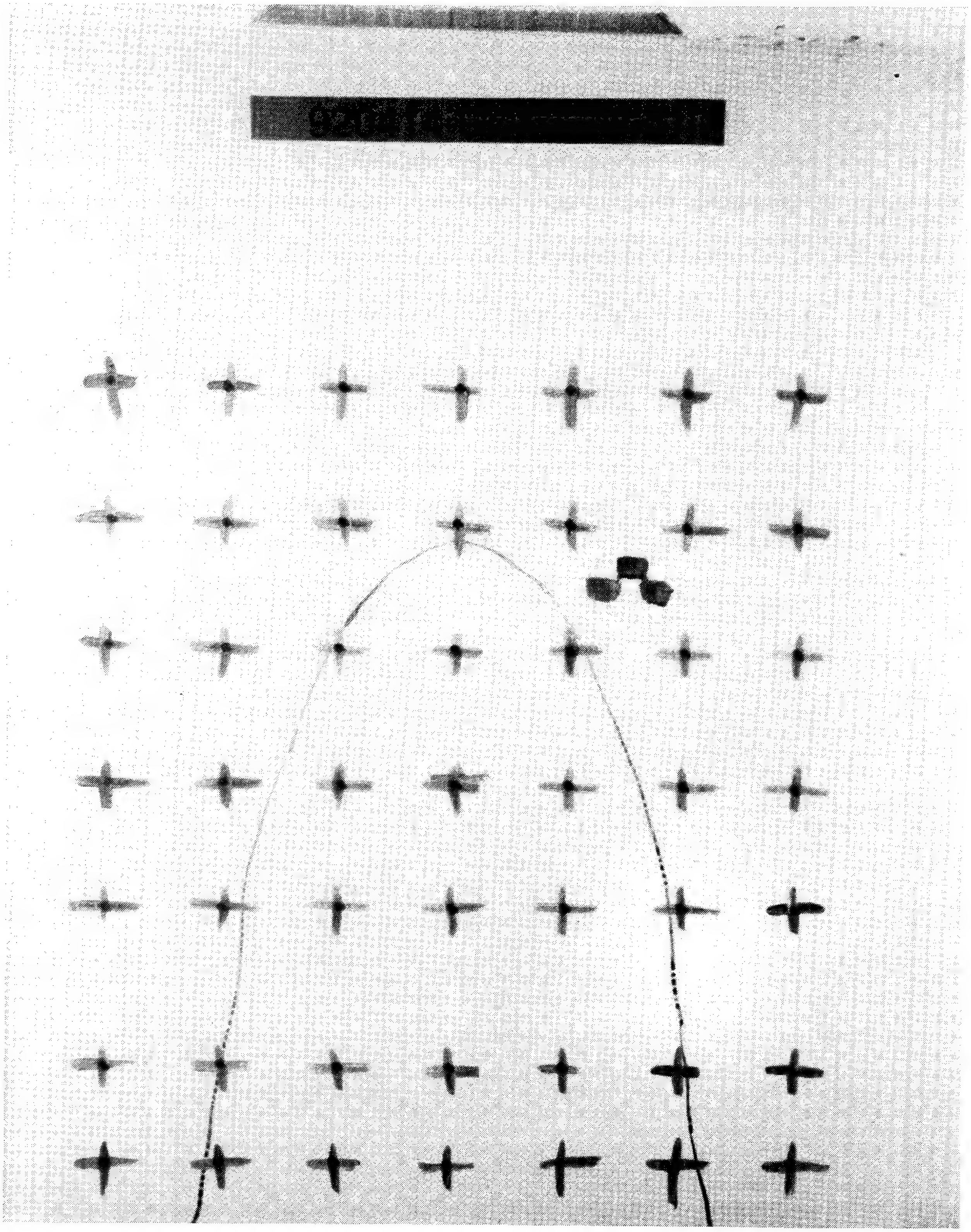

Figure 106. Posttest Photograph of Panel 920414-08 MX2048 (277 knots).

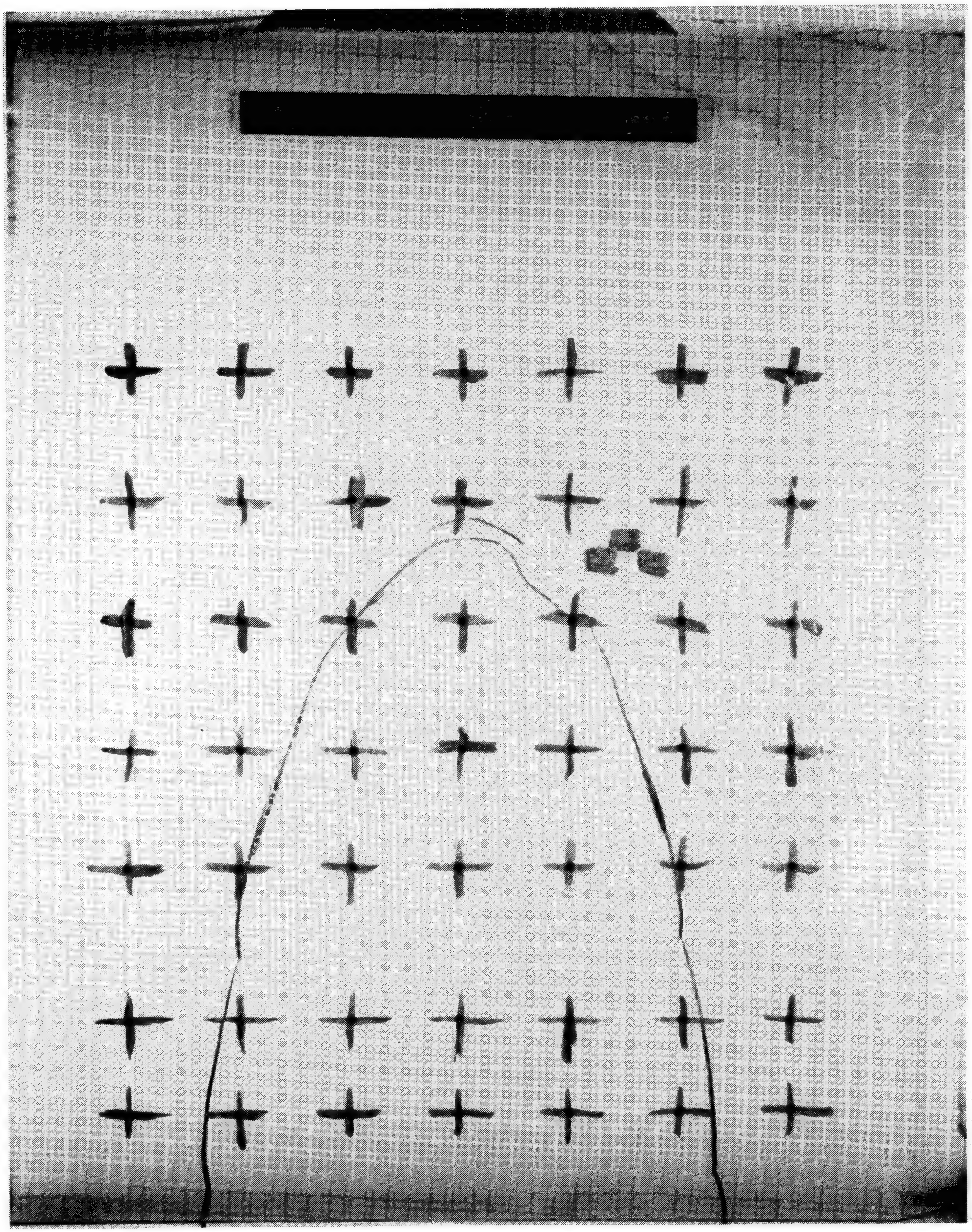

Figure 107. Posttest Photograph of Panel 920416-05 MX2047 (302 knots).

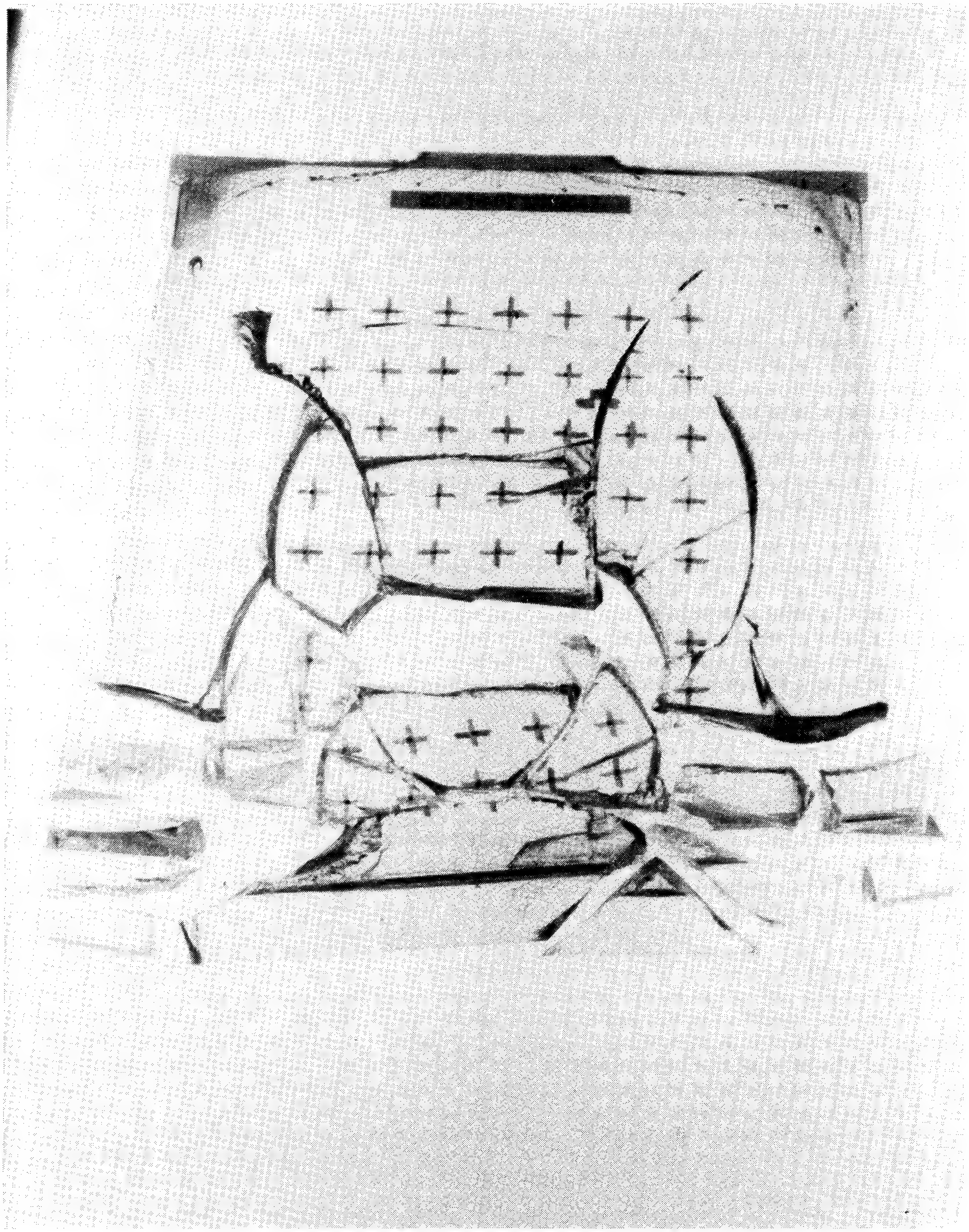

Figure 108. Posttest Photograph of Panel 920416-07 MX2047 (357 knots).

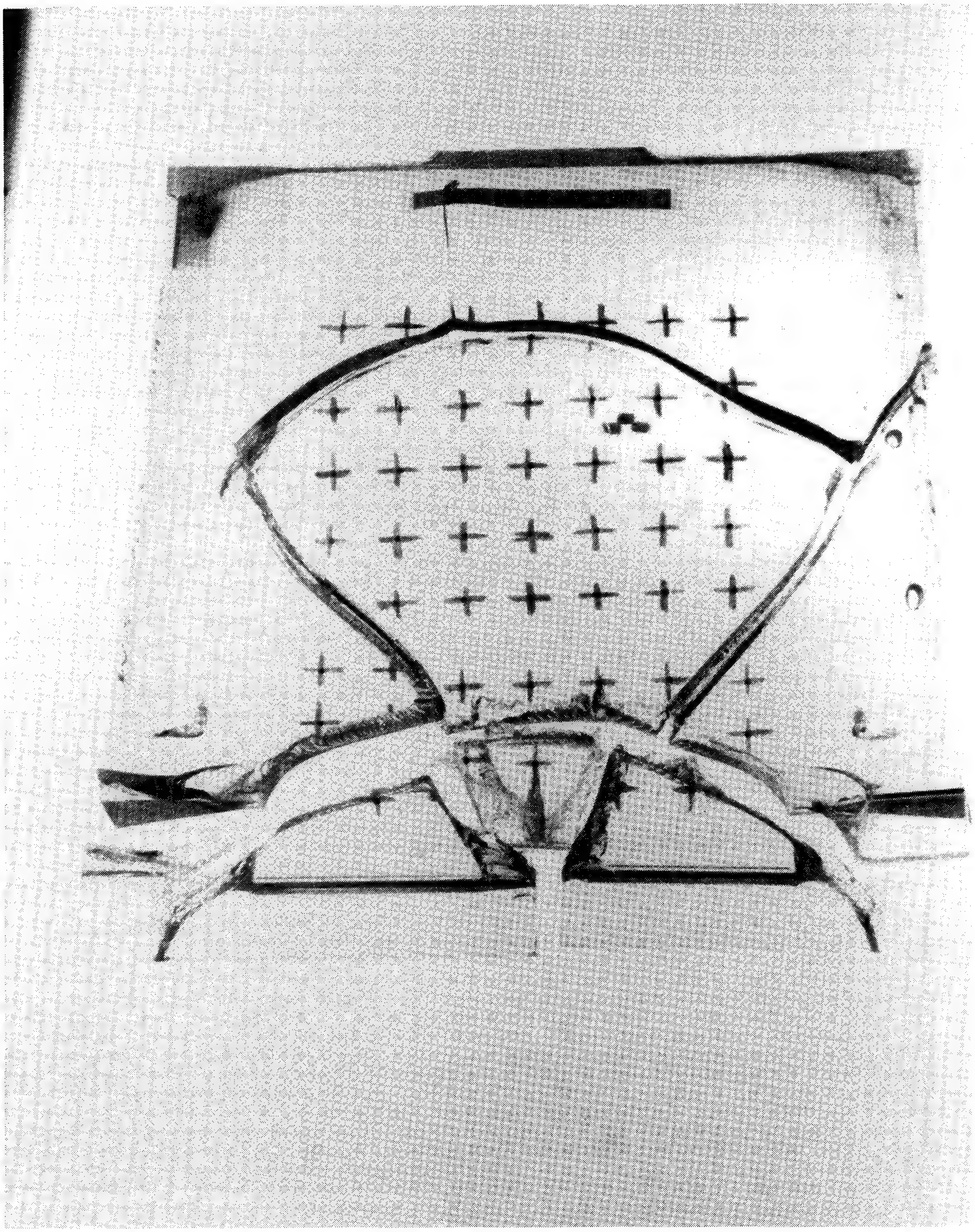

Figure 109. Posttest Photograph of Panel 920416-08 MX2047 (327 knots).

APPENDIX E.

STRESS-STRAIN CURVES FOR INDIVIDUAL RESINS

The following figures show typical stress-strain curves for each combination of resin, panel thickness, and strain rate. Figures 110 through 118 show engineering stress-strain curves based on point-by-point averages of data from several tests. Failure points indicated in the figures are at the average failure strain from each set of specimens. Figures 119 through 127 show true stress-strain curves up to the yield point. Dotted lines in these figures are ±2 sample standard deviation from average.

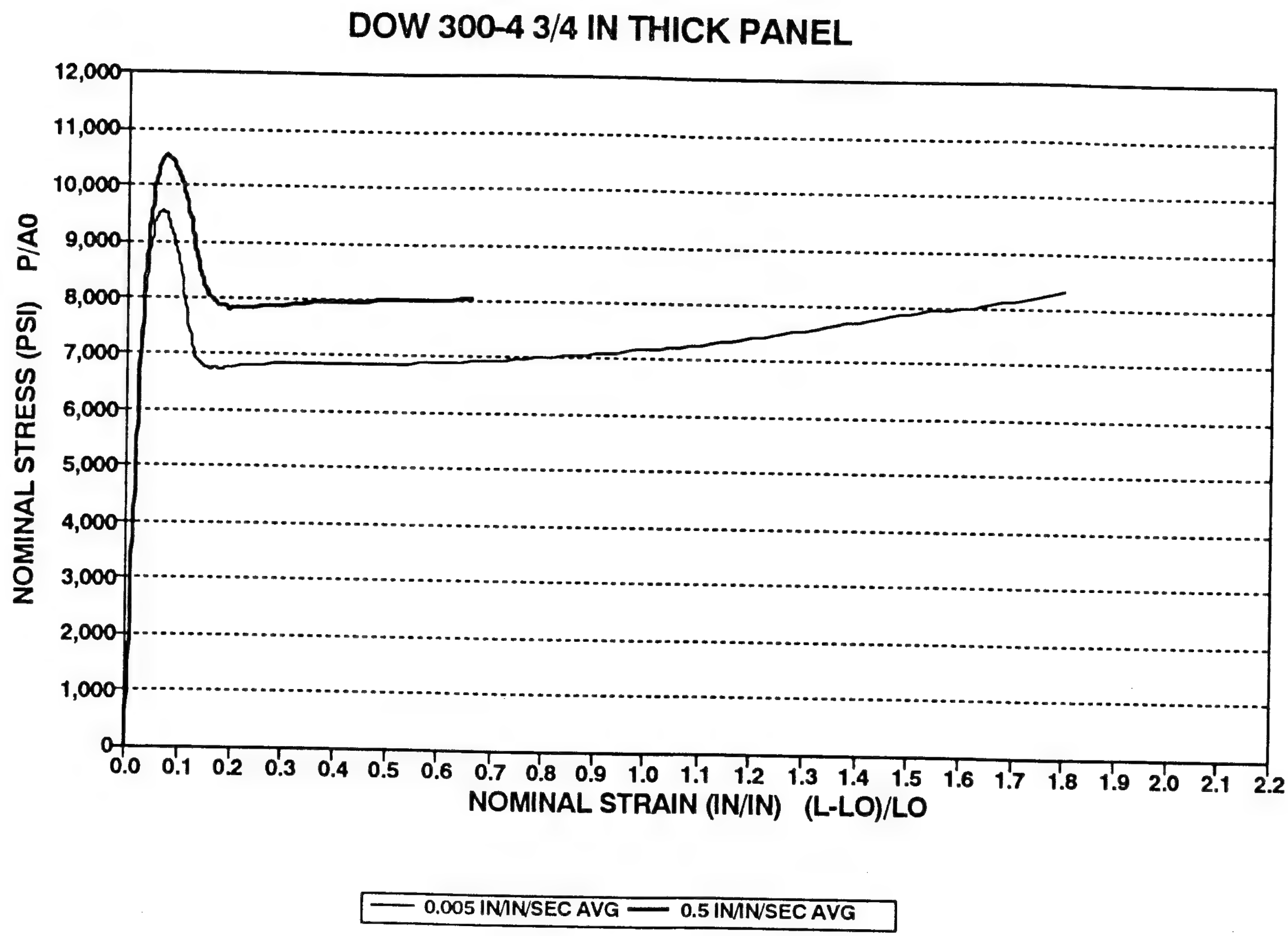

Figure 110. Engineering Stress-Strain Curves from 3/4-Inch Thick Flat Panels of Dow 300-4.

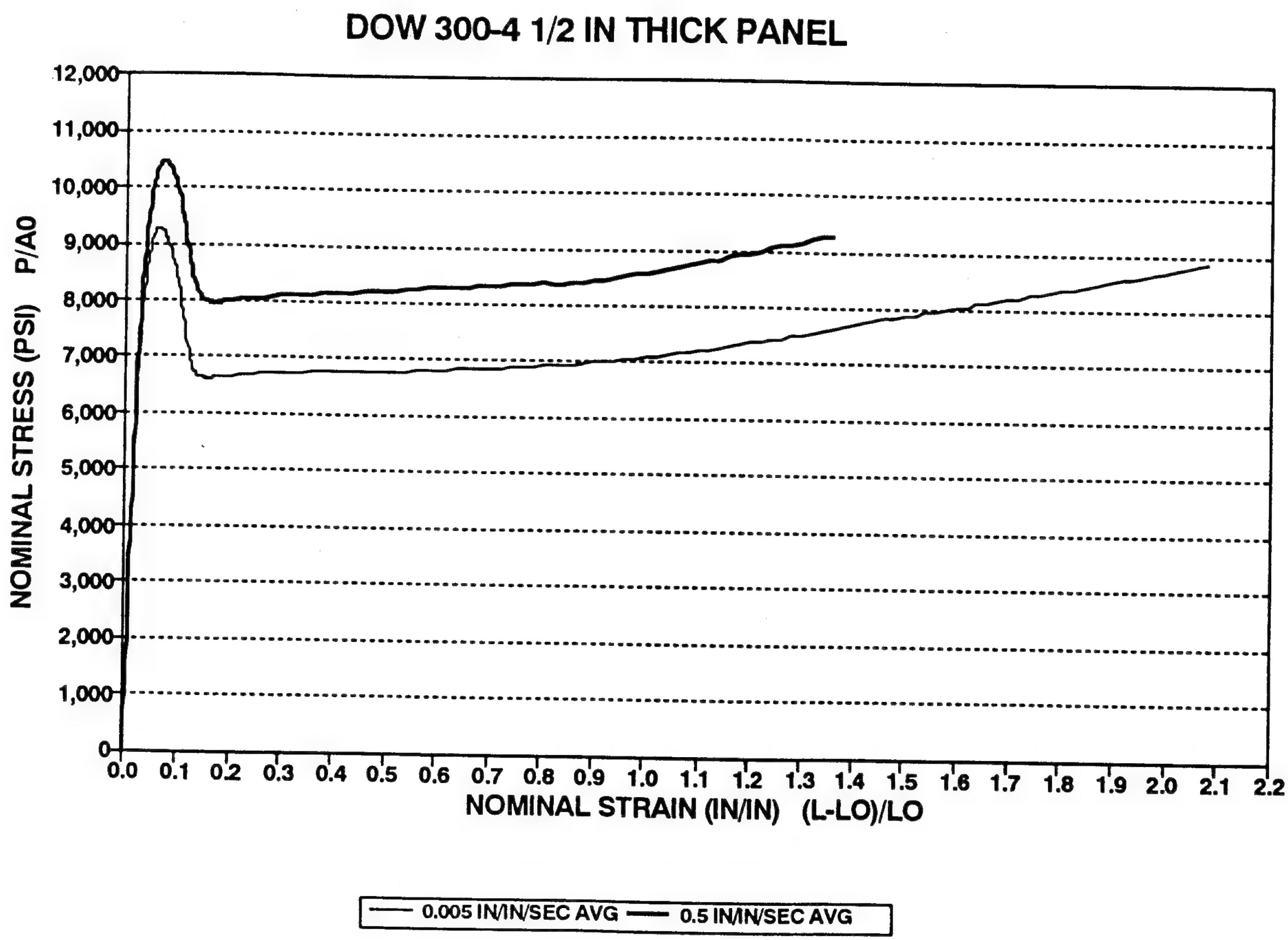

Figure 111. Engineering Stress-Strain Curves from 1/2-Inch Thick Flat Panels of Dow 300-4.

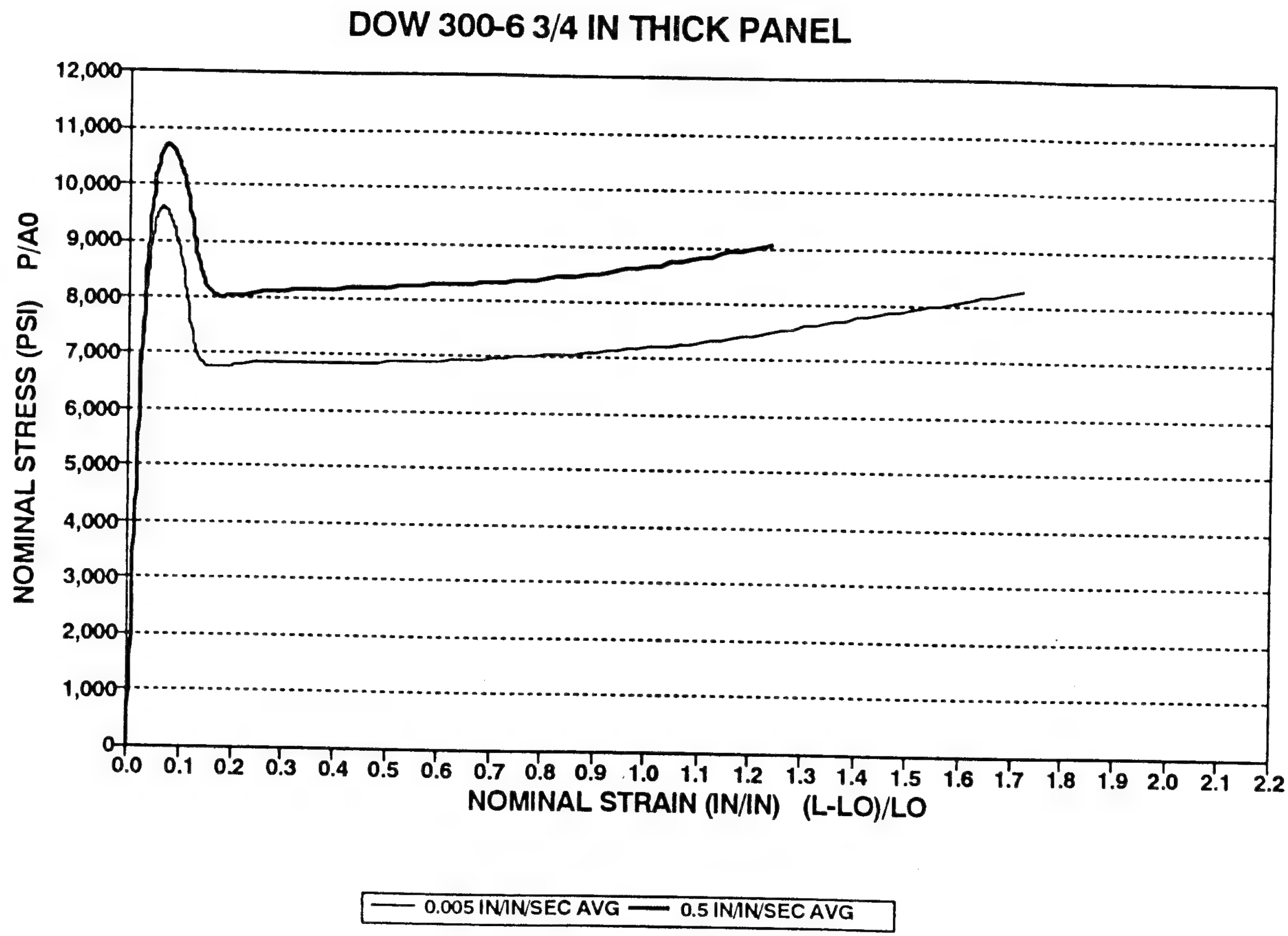

Figure 112. Engineering Stress-Strain Curves from 3/4-Inch Thick Flat Panels of Dow 300-6.

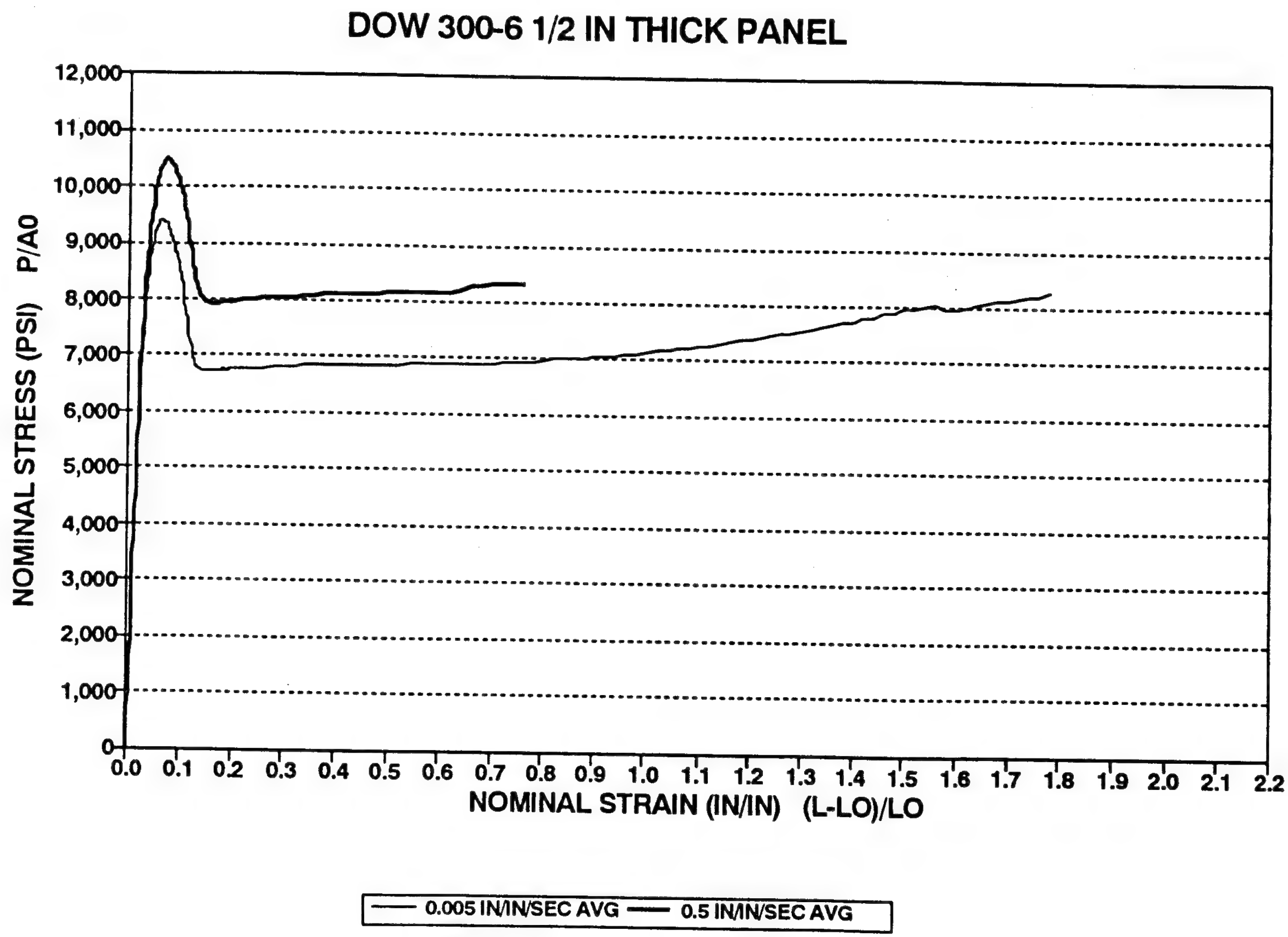

Figure 113. Engineering Stress-Strain Curves from 1/2-Inch Thick Flat Panels of Dow 300-6.

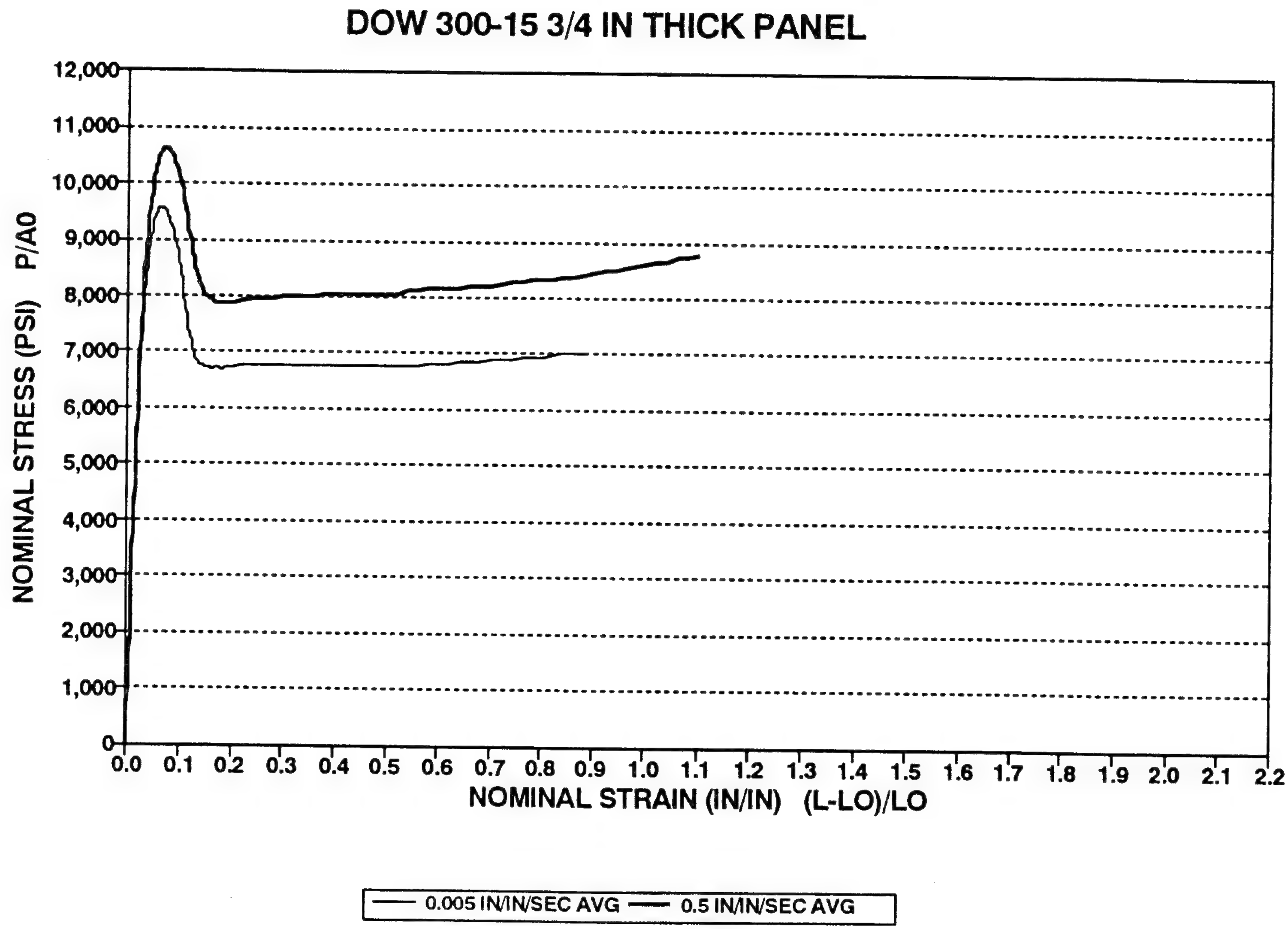

Figure 114. Engineering Stress-Strain Curves from 3/4-Inch Thick Flat Panels of Dow 300-15.

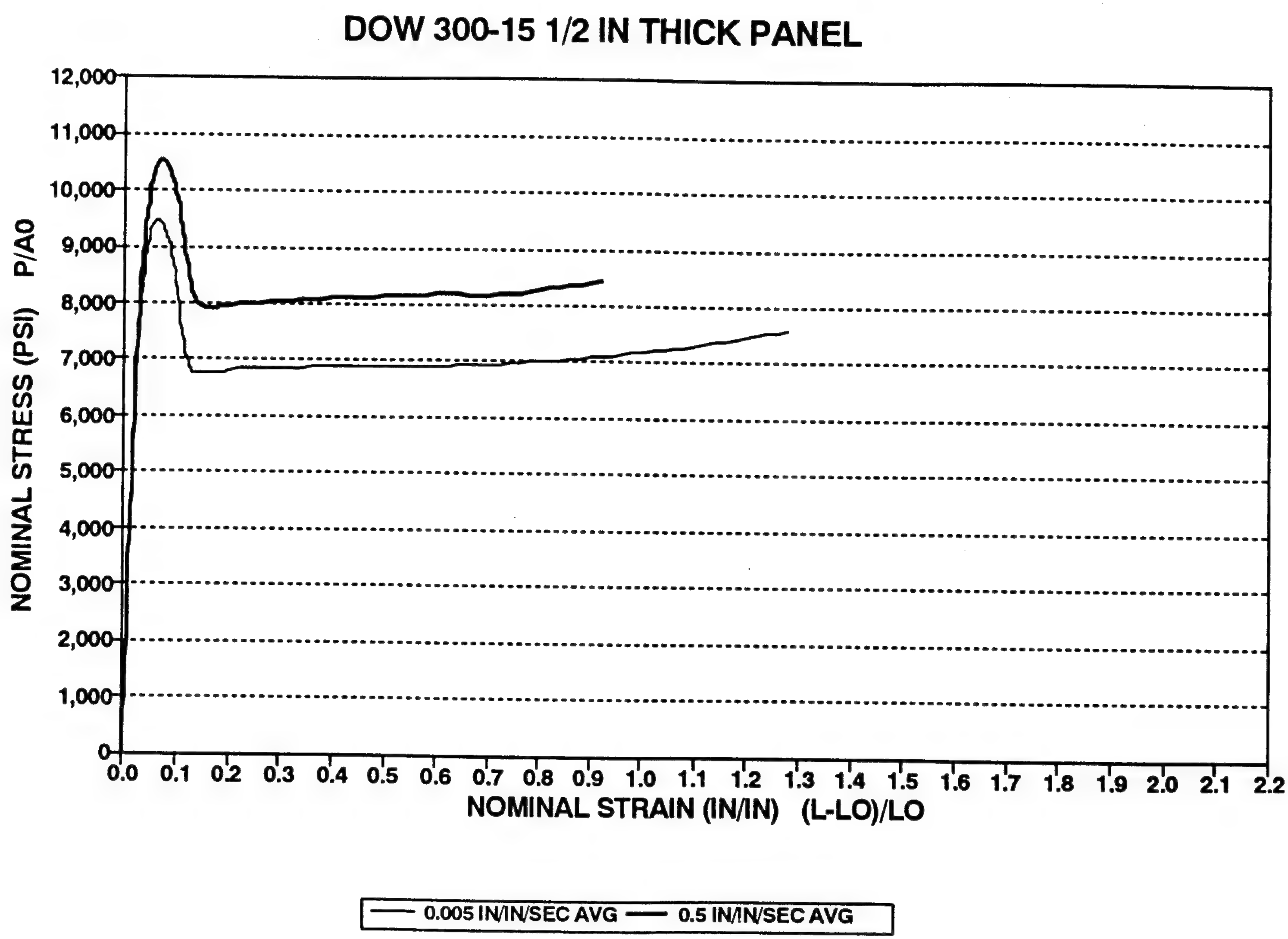

Figure 115. Engineering Stress-Strain Curves from 1/2-Inch Thick Flat Panels of Dow 300-15.

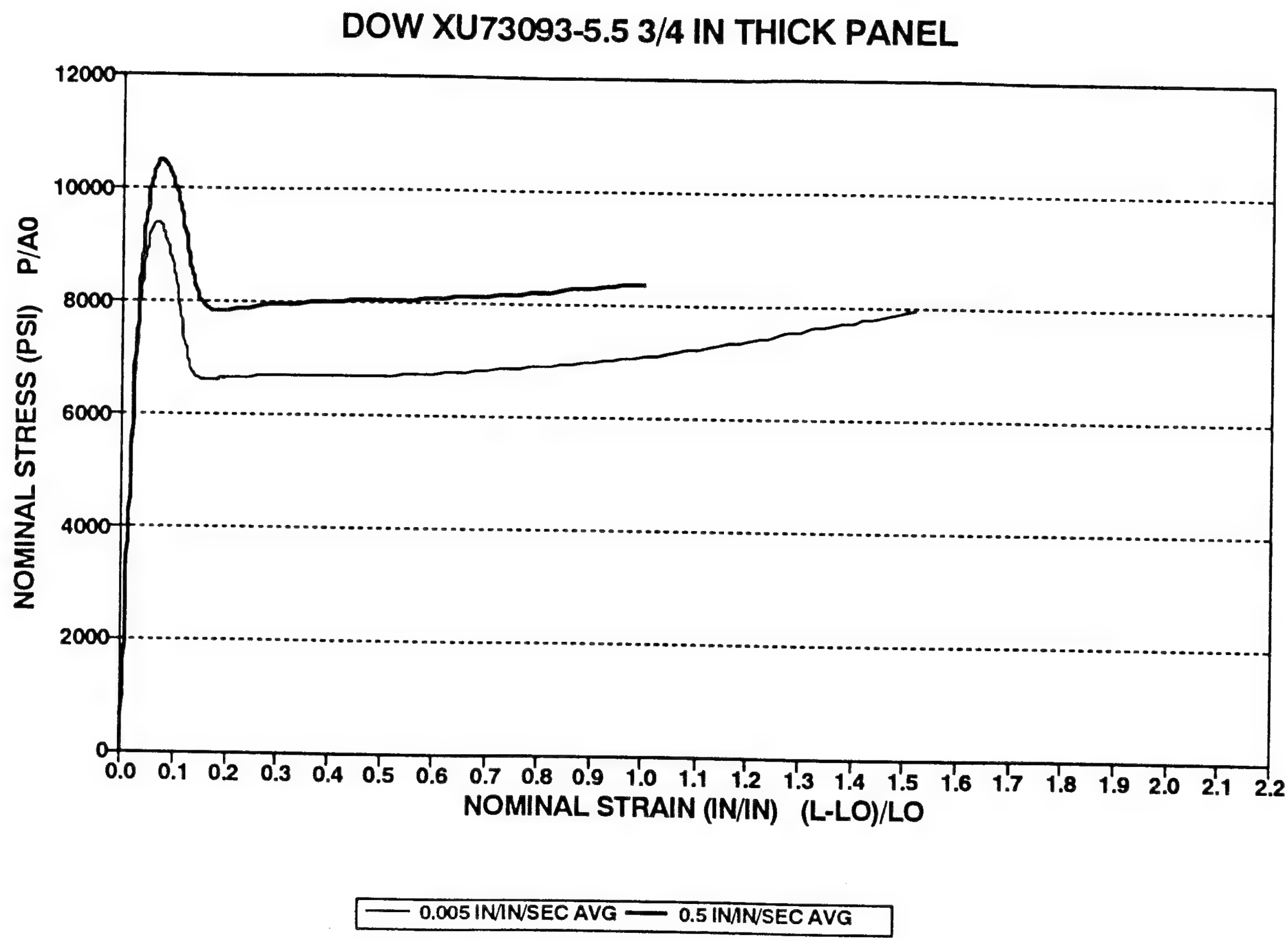

Figure 116. Engineering Stress-Strain Curves from 3/4-Inch Thick Flat Panels of Dow XU73093-5.5.

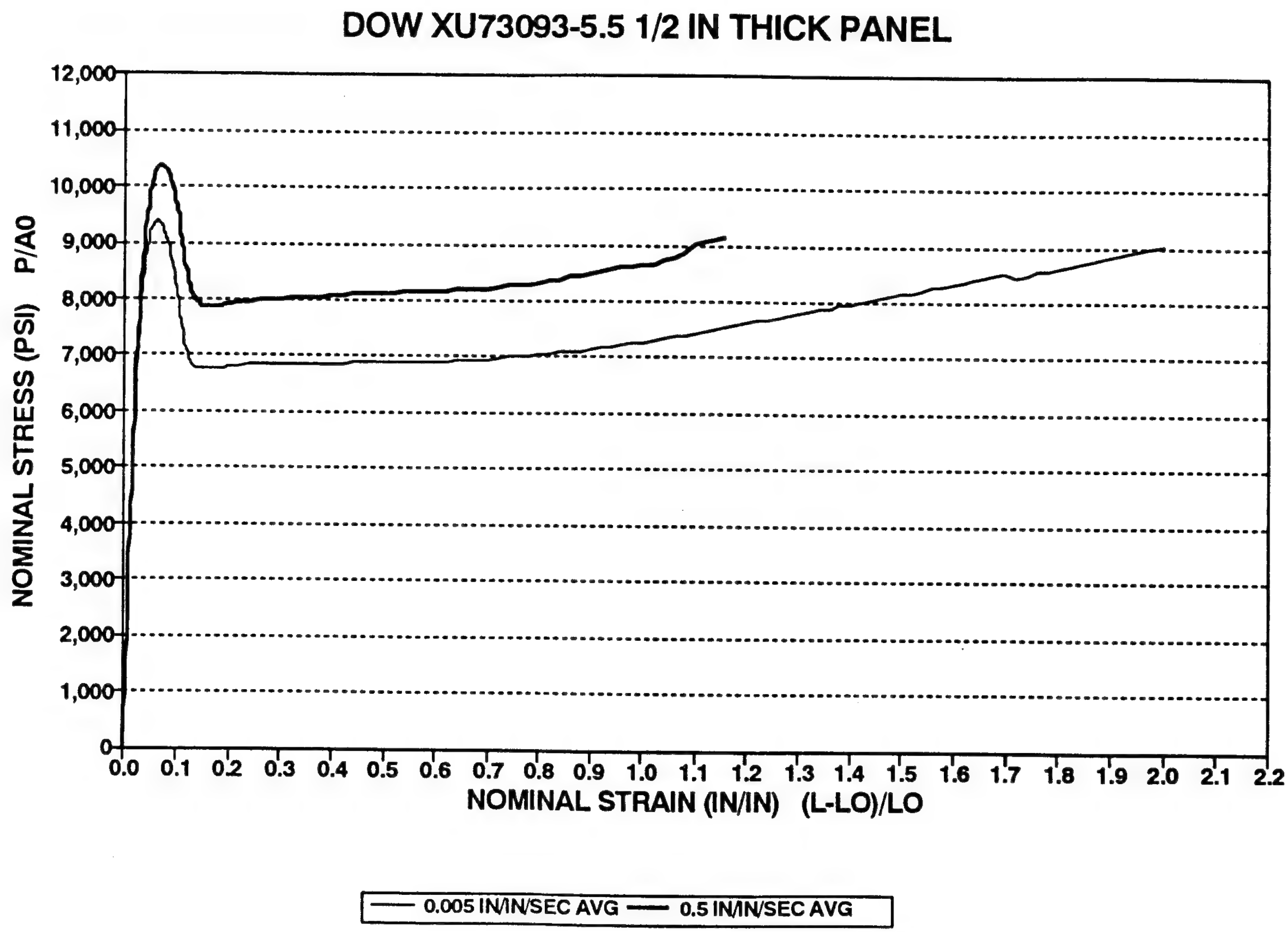

Figure 117. Engineering Stress-Strain Curves from 1/2-Inch Thick Flat Panels of Dow XU73093-5.5.

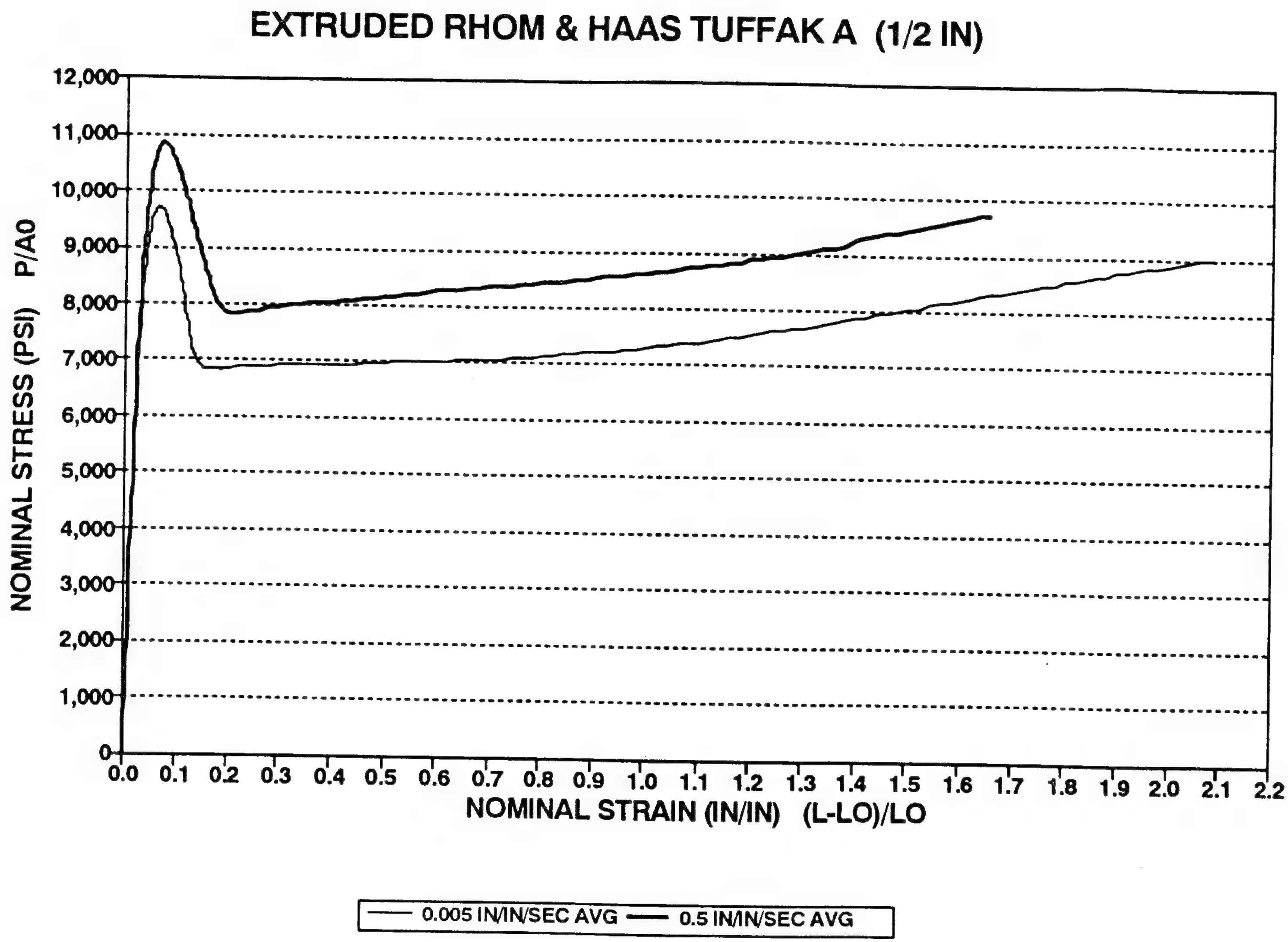

Figure 118. Engineering Stress-Strain Curves from 1/2-Inch Thick Flat Panels of Extruded Rhom & Haas Tuffak A.

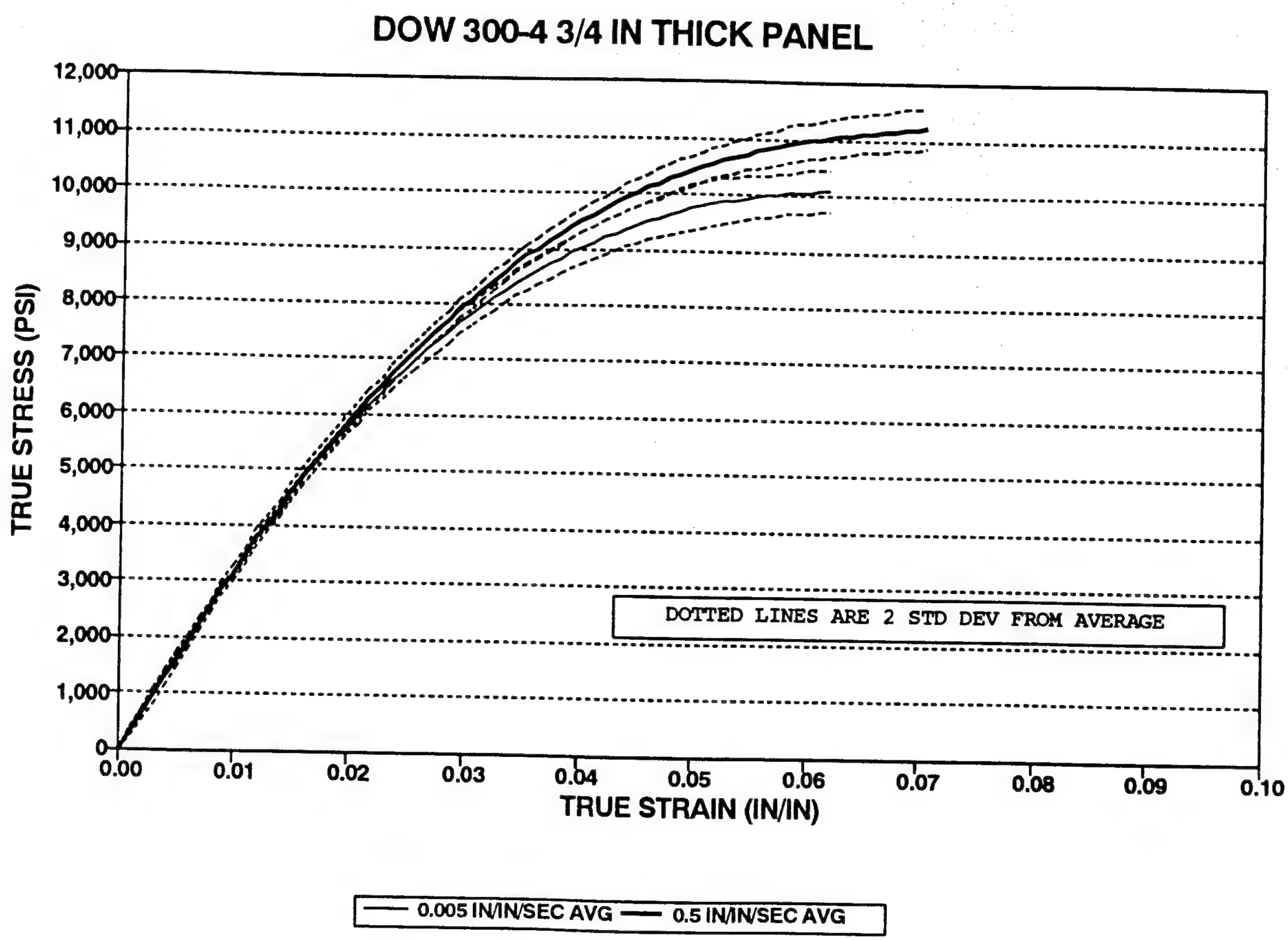

Figure 119. True Stress-Strain Curves from 3/4-Inch Thick Flat Panels of Dow 300-4.

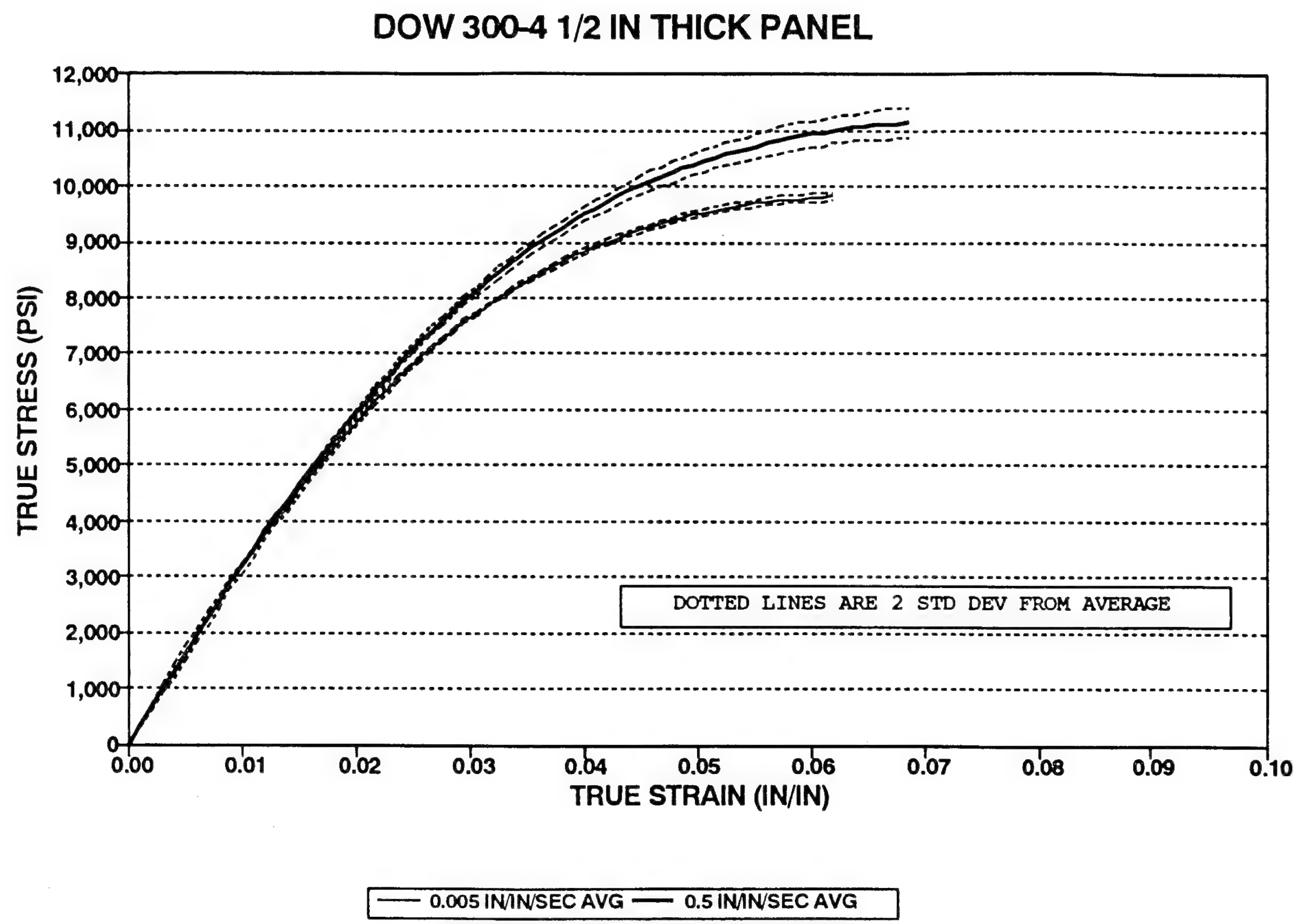

Figure 120. True Stress-Strain Curves from 1/2-Inch Thick Flat Panels of Dow 300-4.

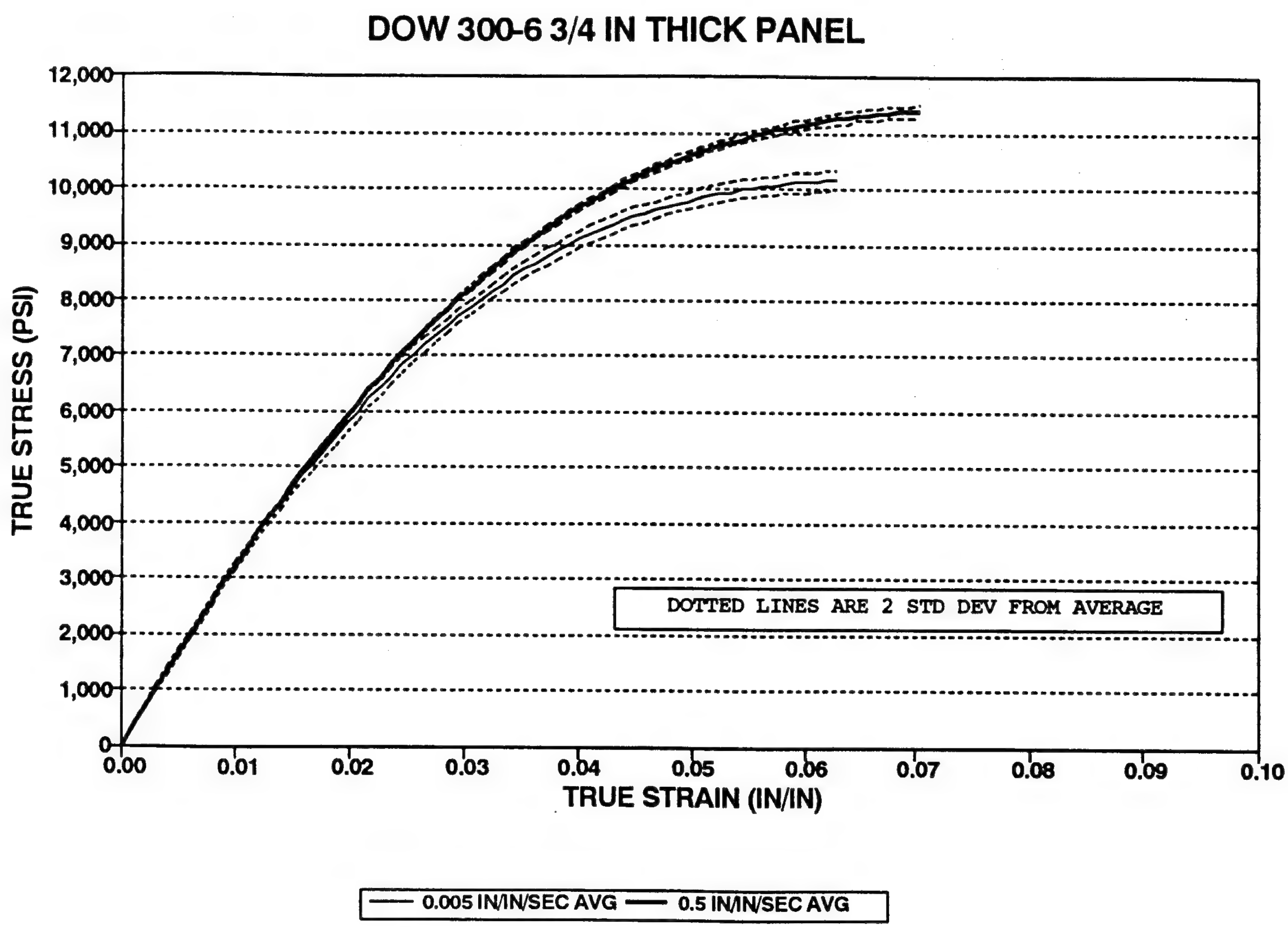

Figure 121. True Stress-Strain Curves from 3/4-Inch Thick Flat Panels of Dow 300-6.

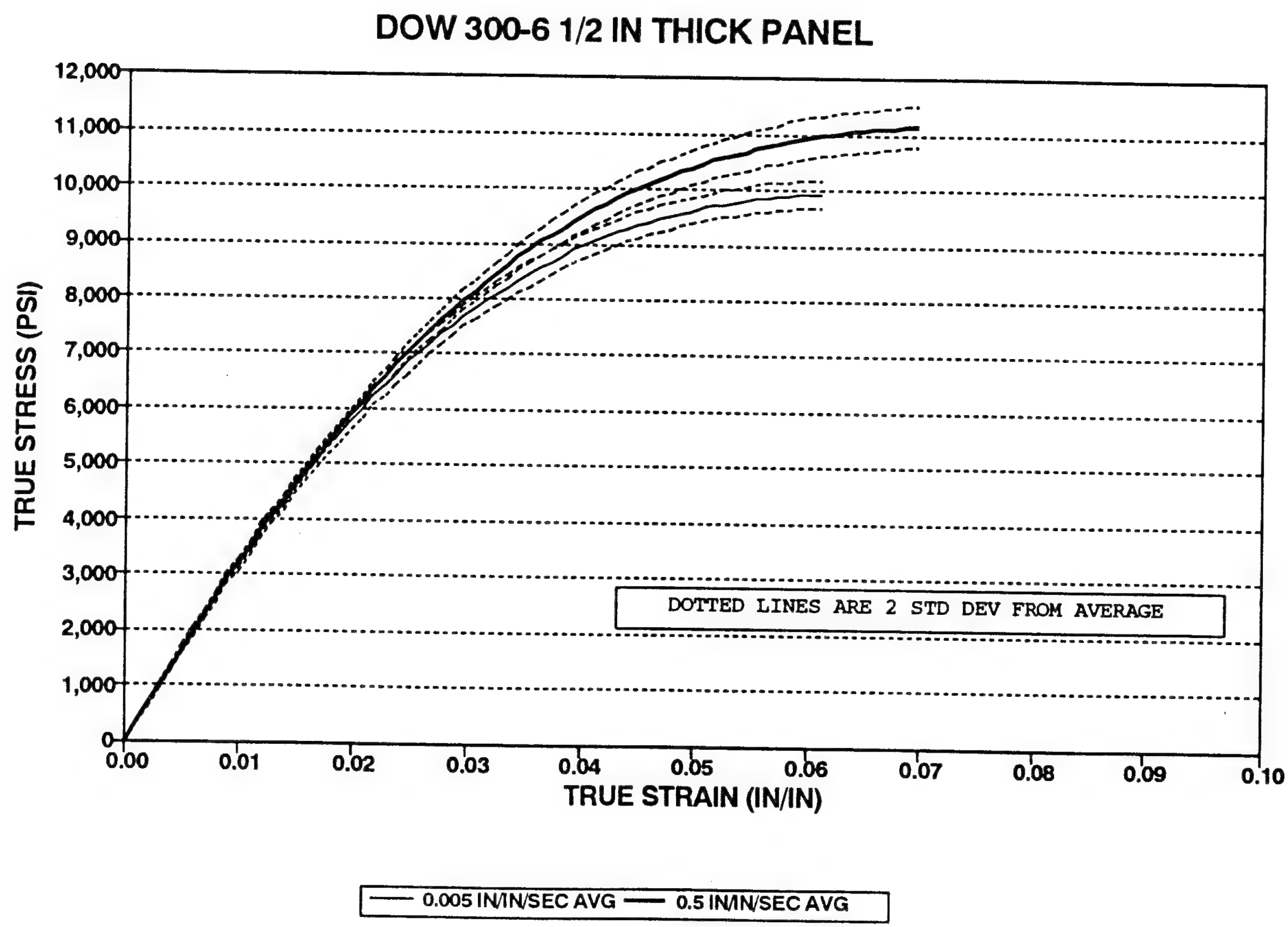

Figure 122. True Stress-Strain Curves from 1/2-Inch Thick Flat Panels of Dow 300-6.

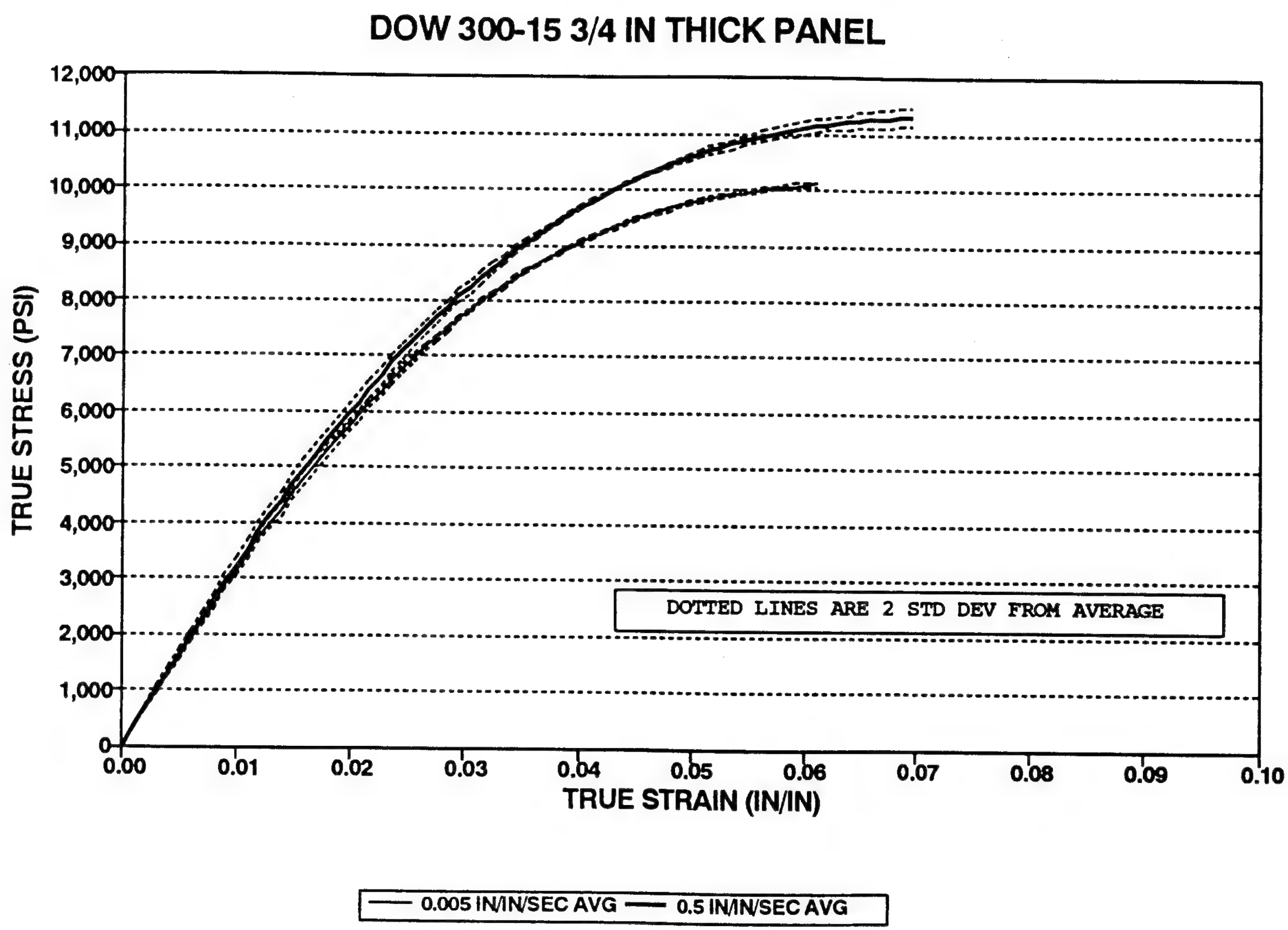

Figure 123. True Stress-Strain Curves from 3/4-Inch Thick Flat Panels of Dow 300-15.

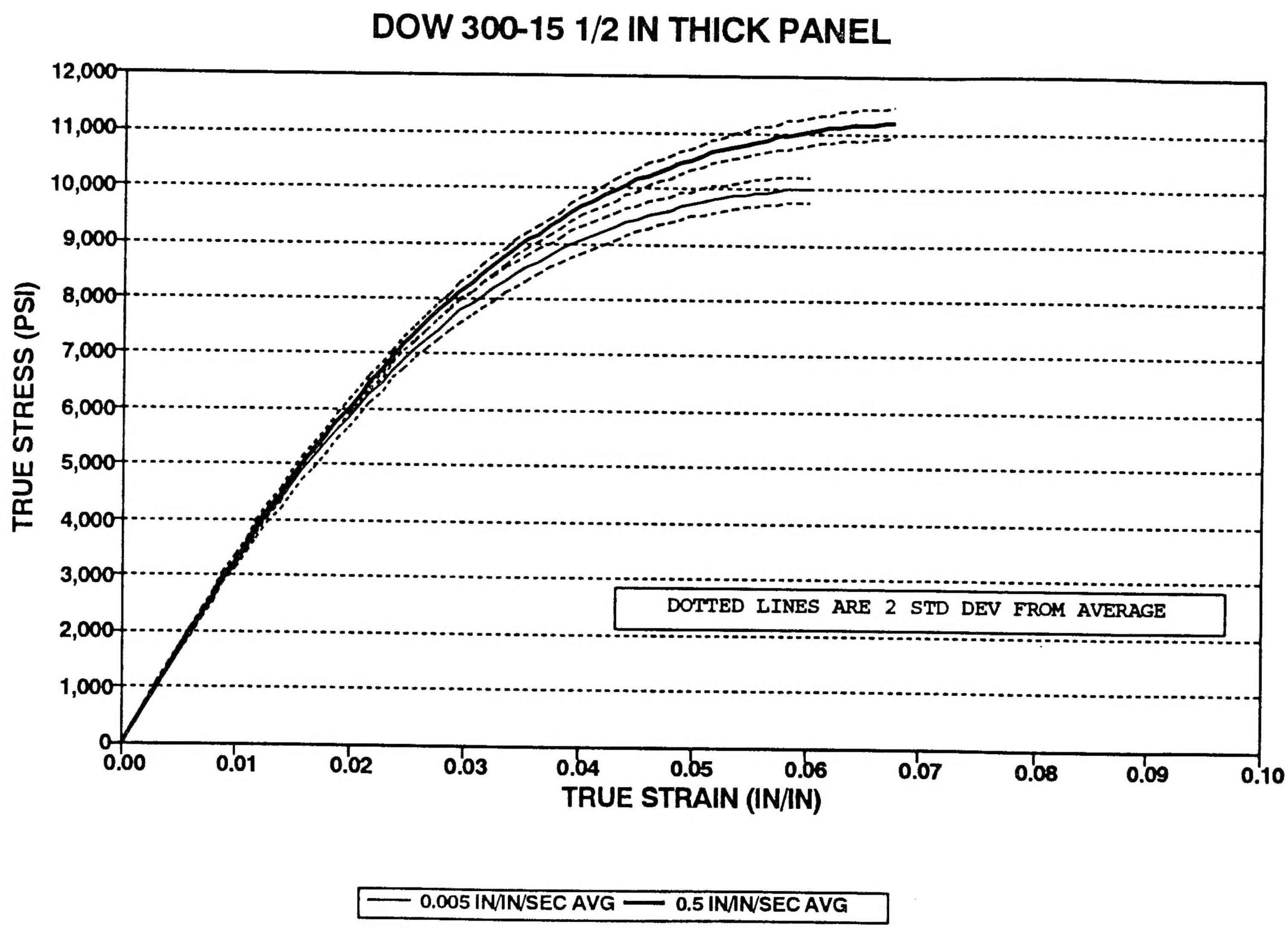

Figure 124. True Stress-Strain Curves from 1/2-Inch Thick Flat Panels of Dow 300-15.

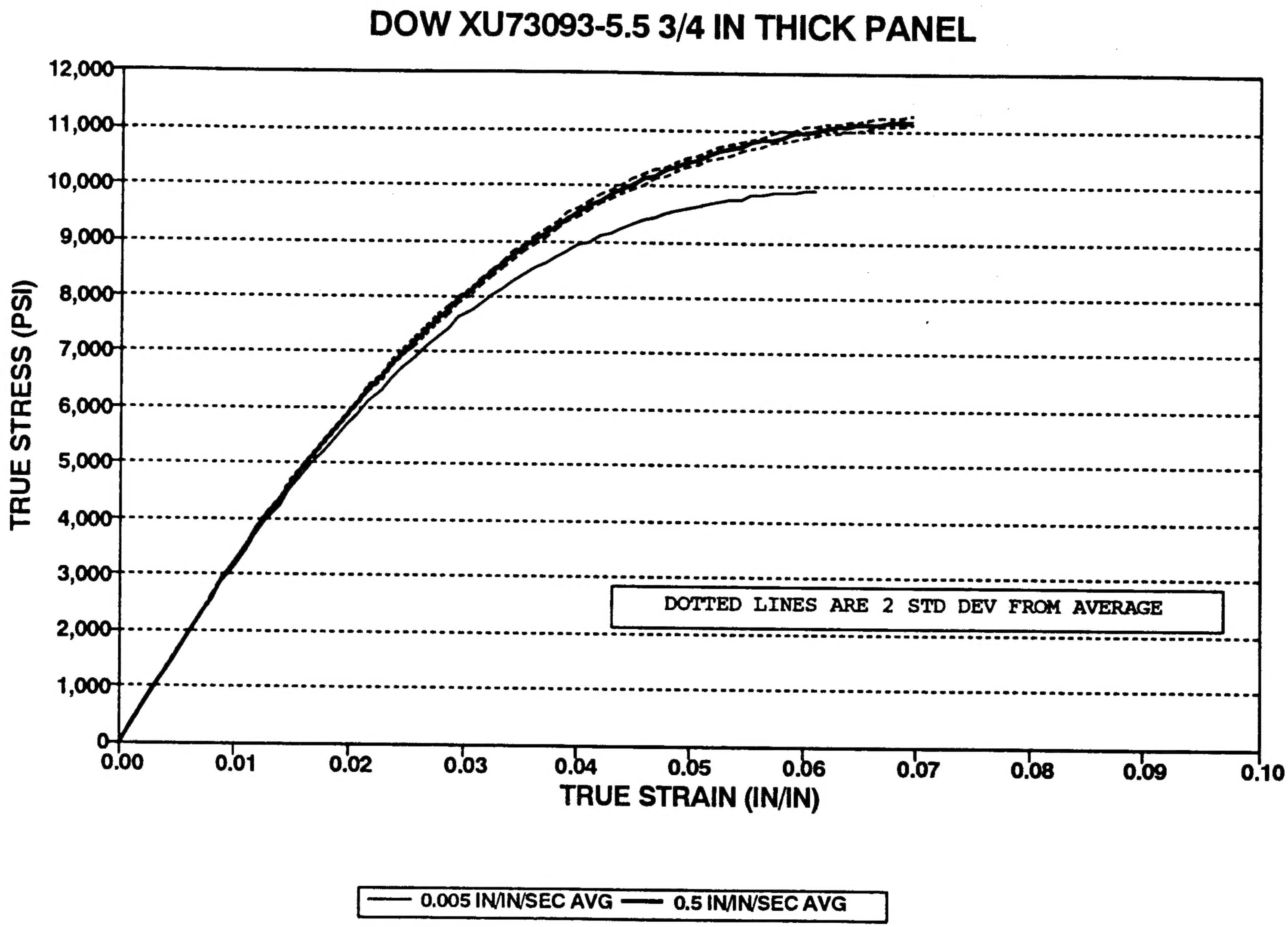

Figure 125. True Stress-Strain Curves from 3/4-Inch Thick Flat Panels of Dow XU73093-5.5.

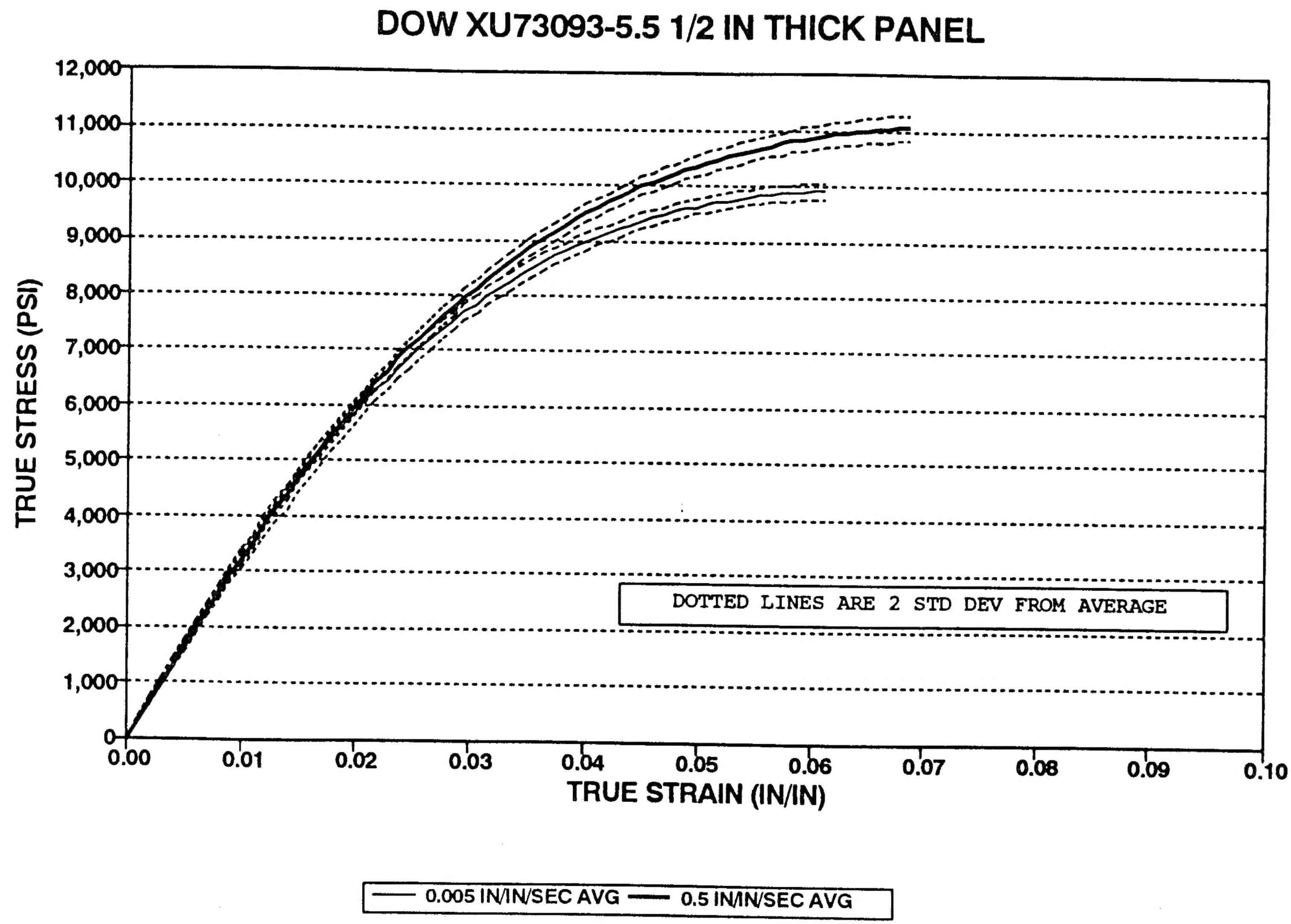

Figure 126. True Stress-Strain Curves from 1/2-Inch Thick Flat Panels of Dow XU73093-5.5.

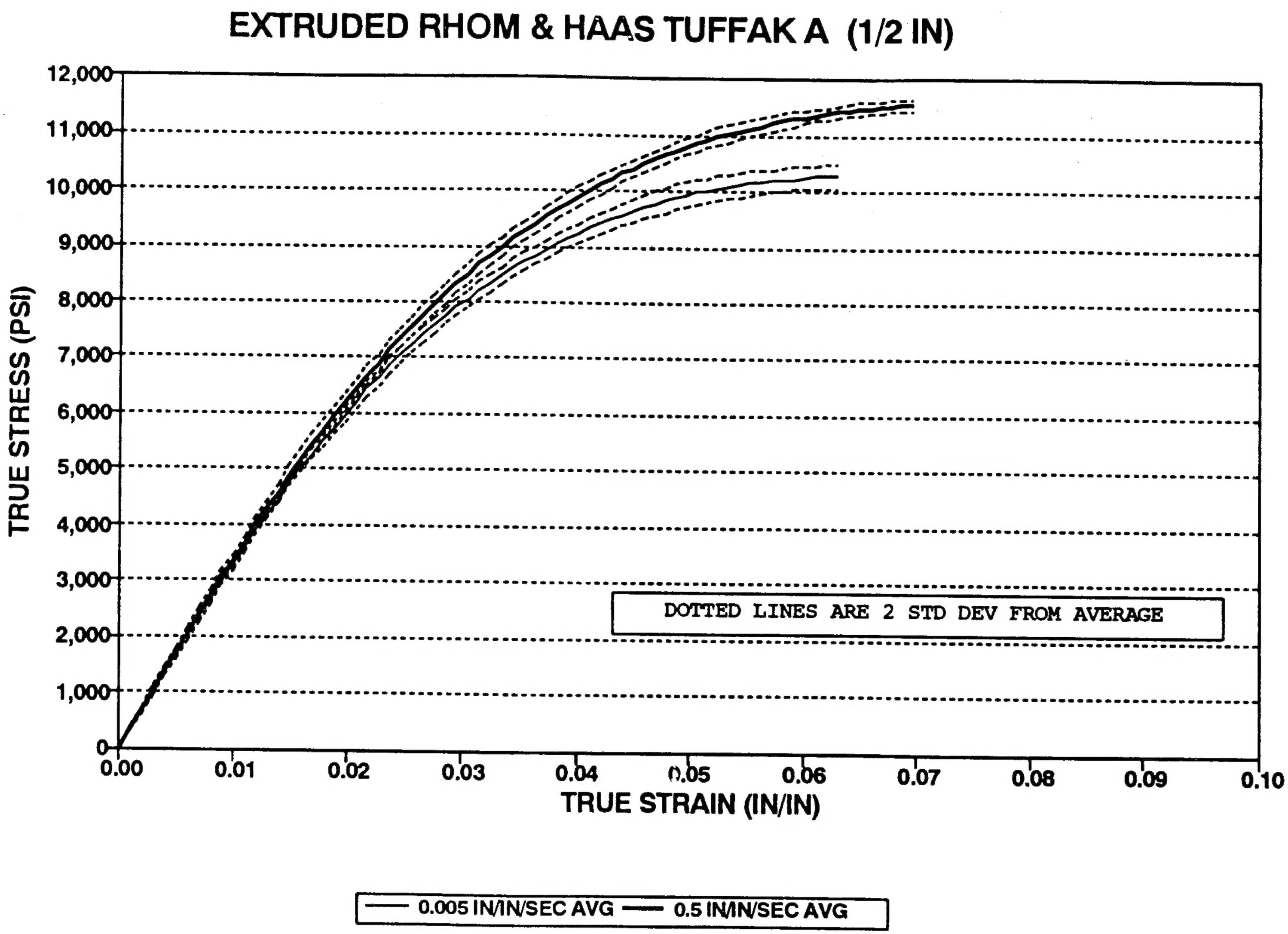

Figure 127. True Stress-Strain Curves from 1/2-Inch Thick Flat Panels of Extruded Rhom & Haas Tuffak A.

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